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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1957 ANNUAL MEETING

AT

NEW YORK CITY

January 30 through February 2, 1957

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January 30, 1957 Series II, Vol. 2, No. 1

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1957 Annual Meeting at New York, January 30–February 2, 1957

THE 1957 Annual Meeting of the American Physical Society will be held in New York City, in halls of the Hotel New Yorker and of the adjacent Manhattan Center, on Wednesday, Thursday, Friday, and Saturday, **January 30 and 31 and February 1 and 2.** The American Association of Physics Teachers (hereinafter to be designated as AAPT) will join with us as heretofore in the Ceremonial Session and at the banquet, but we shall lack some of the glamor of last year's joint convention with the American Institute of Physics and the rest of the Founder Societies. From last year we continue the practice of lengthening our own meeting to four days instead of the former three, and this is so necessary a step that one wonders how we avoided it earlier. Ours is a somewhat larger programme than even last year's, despite the fact that the extra attractions of the Institute's programme are now wanting. Nevertheless the Secretary has just managed to squeeze the sessions, other than the Ceremonial Session, into the halls available in the Hotel New Yorker. This has the advantage of convenience and the disadvantage that some of the sessions will almost certainly be overcrowded. Those who find the disadvantage outweighing the advantage may take comfort from the thought that we shall very likely never again be able to confine our New York meetings within the walls of a single hotel. This year the scantiness of space has curtailed the list of invited papers far below what was hoped.

The administration of this meeting is in the able hands of S. A. Korff, Chairman of the Local Committee, and of the American Institute of Physics, to whom we owe our warmest thanks.

Hotel. The official hotel is the New Yorker. All reservations are to be made by use of the form on page 77 of this Bulletin, reprinted from the Chicago Bulletin.

The **registration desk** will be located on the mezzanine of the Hotel New Yorker. The registration fee will be two dollars: these Annual Meetings are our most expensive, because of the need of renting so capacious a hall as the Manhattan Center for the Ceremonial Session and because of other expenses required when sessions are held in a hotel. Banquet tickets will be sold at the registration desk. Post-deadline papers, if any, will be announced on a blackboard near the registration desk; and there will be a blackboard for notice of messages and possible alterations in the programme.

The **banquet** of the American Physical Society and of the AAPT will be held on Friday evening in the Terrace Room of the Hotel New Yorker. The after-dinner speakers will be M. J. Kelly and R. R. Wilson, and the 1957 Oliver E. Buckley Solid-State Physics Prize will be awarded to Charles Kittel. Since this banquet is held on the third evening of the meeting, we are not requesting advance reservations. Please buy your tickets early at the registration desk: the price will be $5.50.

The **joint ceremonial session of the two Societies** will be held in Manhattan Center on Friday afternoon, beginning at two o'clock. Our retiring President, E. P. Wigner, will deliver his address entitled "Relativistic Concepts and Quantum Phenomena." The Oersted Medal of AAPT will be conferred on Mark Zemansky, who will respond with a speech named "Fashions in Thermodynamics." The fifteenth Richtmyer Memorial Lecture, entitled "Antinucleons" will be given by Emilio Segrè.

The **Oliver E. Buckley Solid-State Physics Prize** for 1957 will be awarded at the banquet to Charles Kittel, who will deliver, under the title "Role of Magnetic-Resonance Studies in the Physics of Solids," the Oliver E. Buckley Lecture in the Grand Ballroom at 11:45 A.M. on Friday.

Invited papers on the general programme are by E. Ambler, L. Apker, H. A. Bethe, B. Bleaney,

L. M. Bollinger, G. Borelius, L. Cranberg, W. A. Fowler, J. B. French, C. D. Jeffries, A. K. Mann, N. Kurti, Henry Margenau, Leona Marshall, W. A. Nierenberg, R. Novick, F. M. Pitkin, Frederick Reines, L. D. Roberts, Bruno Rossi, Igal Talmi and G. K. Wertheim.

Our **Division of Electron Physics** has arranged a group of invited papers by W. P. Allis, N. Bloembergen, and E. S. Rittner, to be held on Friday morning; its Business Meeting will be a part of this session.

Our **Division of Solid-State Physics** has arranged a Symposium on the topic "Imperfections Produced by Crystal Growth." It will be held on Friday afternoon, and the speakers will be B. L. Averbach, W. C. Dash, P. H. Egli, W. G. Pfann, and W. A. Tiller.

Our **Division of Fluid Dynamics** has arranged a Symposium on the topic "Boundary Layer Flow." It will be held on Thursday morning, and the speakers are to be J. C. Evvard, C. C. Lin, F. R. Riddell, and G. B. Schubauer. The Business Meeting of the Division will be a part of this session.

The American Institute of Physics will conduct a **Placement Service Register** on the 5th and 6th floors of the Hotel New Yorker, January 30–February 2. This year, for the first time, the Register will be open until 9 P.M., Wednesday, Thursday, and Friday evenings.

There will be a display of scientific instruments, laboratory apparatus, teaching aids, and technical books, and all **exhibits** will be located on the mezzanine of the Hotel New Yorker immediately adjacent to the registration area. The exhibit will be open from 9 A.M. to 6 P.M. on Wednesday, Thursday, and Friday, January 30–February 1st. All are cordially invited to visit.

Three hundred and seventy-six contributed papers are distributed among thirty-four sessions. In this task of classification (in the old sense of the word) invaluable aid has been given to the Secretary by the Deputy Secretary and by P. Kusch, L. M. Lederman, Robert Serber, and C. S. Wu.

The **Business Meeting of the Society** will be held at 4:45 P.M. on Wednesday in the Grand Ballroom.

The **Council of the American Physical Society will meet on** Tuesday (January 29) at 10:30 A.M. in the building of the American Institute of Physics at 57 East 55th Street, New York 22, New York, unless contrary notice is sent to its members.

Post-deadline ten-minute papers pertaining to very recent achievements of very special importance will be considered for admission to a special supplementary programme if the abstracts are received at the office of the Society not later than Friday, January 25. The titles of such as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule at the end of Session Z. The abstracts will not be published. Those who submit post-deadline papers will not be able to find out whether their papers are admitted until they see the blackboard.

Preliminary announcement of the **Philadelphia meeting** appears on page 79 of this Bulletin, and the **calendar of meetings** for the remainder of 1957 on page 79 with instructions for the preparation of abstracts.

Errata pertaining to the content of this issue will be published in a subsequent issue of this Bulletin if received not later than Monday, February 4, by Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York. Do not send in your abstract marked with corrections! Write out your corrections in the form "Instead of . . . read. . . ." Add nothing.

KARL K. DARROW, *Secretary*
American Physical Society
Columbia University
New York 27, New York

EPITOME OF THE 1957 ANNUAL MEETING

(Personal names are those of invited speakers.)

Wednesday Morning

A. Bollinger, Cranberg, Reines, Mann. Grand.
B. Muons, pions, "strange particles." Terrace.
BA. Magnetism, I. Panel.
C. Accelerators. North.
CA. Theoretical physics, I: quantum and relativity theory. Empire.
D. Special topics of nuclear physics. Boston-Washington.

Wednesday Afternoon

E. Neutron physics and general nuclear physics. Boston-Washington.
EA. General solid-state physics; Apker. Grand.
F. "Strange particles." Terrace.
FA. Magnetism, II; ferroelectricity. Panel. (1:45 P.M.)
G. Radioactive nuclei. Empire.
GA. Theoretical physics, II: nuclear theory. North.

Wednesday Afternoon at 4:45

Business Meeting of American Physical Society. Grand.

Thursday Morning

H. Division of Fluid Dynamics: boundary layer flow: Lin, Schubauer, Evvard, Riddell. North.
HA. Bethe, Talmi, French. Grand.
J. Nuclear reactions and nuclear-energy levels, I. Panel.
JA. Magnetic resonance, I. Terrace.
K. Medium-energy scattering and neutron physics. Boston-Washington.
KA. General physics. Empire.

Thursday Afternoon

L. Joint ceremonial session of APS and AAPT: Bethe, Zemansky, Segrè. Manhattan Center.

Friday Morning

M. Magnetic resonance, II; positronium. Terrace.
MA. Theoretical physics, III: "strange particles," other topics. Panel.
N. Division of Electron Physics: Ritner, Bloembergen, Allis. Grand.
N4. Buckley lecture: Kittel. Grand (11:45 A.M.)
NA. Low-energy neutron physics. Boston-Washington.
P. Molecules. Empire.
PA. Fluid dynamics, I. North.

Friday Afternoon

Q. Fluid dynamics, II. North.
QA. Division of Solid-State Physics: imperfections produced by crystal growth: Tiller, Pfann, Dash, Egli, Averbach. Terrace.
R. Theoretical physics, IV: statistical mechanics, collective motions. Boston-Washington.
RA. Nuclear reactions and nuclear-energy levels, II. Panel.
S. Cosmic rays; Rossi. Grand.
SA. Optical and x-ray spectra. Empire.

Friday Evening

Banquet of APS and AAPT: Kelly, Wilson. Terrace.

Saturday Morning

T. Semiconductors, I; Wertheim. Terrace.
TA. Metals; Borelius. Mosaic.
U. Nuclear reactions and nuclear-energy levels, III. Panel.
UA. Theoretical physics, V: high-energy scattering. Boston-Washington.
V. Cryogenics. North.
VA. Nuclear alignment: Kurti, Pipkin, Ambler, Roberts. Grand.

Saturday Afternoon

W. Nuclear spins and moments: Nierenberg, Jeffries, Novick, Bleaney. Grand.
WA. Semiconductors, II. Terrace.
X. Margenau; electron physics. Mosaic.
XA. Nuclear reactions and nuclear-energy levels, IV. Panel.
Y. Theoretical physics, VI: low-energy scattering. Boston-Washington.
Z. Fowler, Marshall; post-deadline papers, if any. North.

PROGRAMME

WEDNESDAY MORNING AT 10:00

Grand Ballroom

(W. W. HAVENS, JR., presiding)

Invited Papers in Nuclear Physics

A1. Problems and Progress in Measuring Cross Sections of Fissile Nuclei. L. BOLLINGER, *Argonne National Laboratory.* (30 min.)

A2. Fast Neutron Spectrometry by Time-of-Flight. L. CRANBERG, *Los Alamos Scientific Laboratory.* (30 min.)

A3. Neutrino Physics. F. REINES, *Los Alamos Scientific Laboratory.* (40 min.)

A4. Recent Work on Rayleigh and Delbrueck Scattering. A. K. MANN, *University of Pennsylvania.* (30 min.)

WEDNESDAY MORNING AT 10:00

Terrace Room

(L. M. LEDERMAN presiding)

Muons, Pions, "Strange Particles"

B1. A Gas Čerenkov Counter for Detection of Fast Cosmic-Ray Particles. R. J. HANSON* AND D. C. MOORE,† *University of Nebraska.*—Measurements of performance have been made on a gas Čerenkov counter[1] with CO_2 at a pressure of 13.1 atmos as the dielectric radiator. The corresponding index of refraction is 1.00569. The efficiency for counting sea-level cosmic-ray μ mesons was determined with the aid of a scintillation and Geiger counter telescope containing adjustable amounts of steel absorber. Particles which passed through the telescope also passed through the radiating gas. Simultaneous measurements were made of the number of particles producing counts in the telescope counters and of the number producing a Čerenkov count in addition to the telescope counts. μ mesons with velocities greater than that of light in the gas were counted with an efficiency of $(86\pm2)\%$. Tests indicated that the efficiency for counting μ mesons with velocities less than that of light in the gas was less than 3%.

* Now at Grinnell College.
† Now at Schlumberger Well Surveying Corporation, Ridgefield, Connecticut.
[1] D. C. Moore and R. J. Hanson, Phys. Rev. **100**, 972(A) (1955).

B2. Momentum Spectrum of Positrons from the Decay of μ^+ Mesons.* L. ROSENSON, *The University of Chicago.*—The momentum spectrum of positrons from μ^+ decay has been examined. The detecting instrument was a 20-atmos hydrogen-filled diffusion cloud chamber, operated in a magnetic field of 7000 gauss. The data has been compared with the spin $\frac{1}{2}$ μ-meson theory of Michel,[1] as modified by Behrends, Finkelstein, and Sirlin[2] to include first-order radiative effects, and with the spin $\frac{3}{2}$ theory of Behrends and Fronsdal.[3] Statistical analysis of the 1300 acceptable events yields the shape parameters $\rho_{\text{Michel}}=0.68\pm0.05$ and $\rho_{\frac{3}{2}}=0.26\pm0.04$. The theoretical spectra described by shape parameters in the vicinity of the best fits are very similar, and this experiment cannot discriminate between the two spin assignments for the μ^+ meson. The result for ρ_{Michel} has been used, along with β-decay data, to place restrictions on the form of the "Universal Fermi Interaction."

* Research supported by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] L. Michel, Proc. Roy. Soc. (London) **63A**, 514 (1950).
[2] Behrends, Finkelstein, and Sirlin, Phys. Rev. **101**, 866 (1956).
[3] R. E. Behrends and C. Fronsdal, "Fermi decay of higher spin particles." The author is indebted to Drs. Behrends and Fronsdal for a copy of their paper prior to its publication.

B3. Neutron Production by Fast μ Mesons in Lead.* B. F. STEARNS,† R. D. SARD, D. R. JONES,‡ AND J. K. DEPAGTER, *Washington University.*—The mean cross section-neutron multiplicity product ($\langle\sigma m\rangle$) for sea-level μ mesons ($pc>1$ Bev) traversing Pb has been measured, a thermalized neutron being detected in delayed coincidence with a penetrating particle.[1] A magnet cloud chamber above the producer and a hodoscope-absorber array below it serve to identify μ-meson interactions. $\langle\sigma m\rangle=(22\pm8)\times10^{-29}$ cm²/nucleon. Theoretical calculations, using the photoneutron yields of Jones and Terwilliger,[2] give $\langle\sigma m\rangle=15\times10^{-29}$ cm²/nucleon for the yield resulting from knock-on showers and $\langle\sigma m\rangle=9\times10^{-29}$ cm²/nucleon for the direct yield from equivalent photons of the μ-meson field. This theory also agrees with the results of underground measurements at higher average momenta.[3] There is no evidence of scattering in excess of Coulomb scattering. Protons which suffer nuclear interactions produce ≥50 neutrons but seldom produce penetrating secondaries, in agreement with the results of Mylroi and Wilson.[3]

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at University of Arkansas.
‡ Now at University of Cincinnati.
[1] H. C. Wilkins, Ph.D. thesis, Washington University (1952); Annis, Wilkins, and Miller, Phys. Rev. **94**, 1038 (1954).
[2] L. W. Jones and K. M. Terwilliger, Phys. Rev. **91**, 699 (1953).
[3] M. G. Mylroi and J. G. Wilson, Proc. Phys. Soc. (London) **A64**, 404 (1951).

B4. Nuclear Absorption of Pi Mesons from Atomic *S* States.* ROBERT KARPLUS AND FRANCIS HALPERN, *University of California, Berkeley.*†—The Galilei invariant nonrelativistic limit of the pseudoscalar meson theory contains a term that

describes the interaction of S-wave mesons with nucleons.[1] It is the fundamental interaction for the nuclear absorption of bound S-state pions. The absorption rate is proportional to the mesonic coupling constant, to the atomic wave function of the pion, and, in the impulse approximation, to the probability of finding a proton in the original nucleus in a nucleon pair with a relative energy of 140 Mev.[2] The ratio of this probability in a larger nucleus (atomic number $Z\sim5$–8) to its value for the deuteron is found to be about $7Z$.[3] If the momentum distribution in a nucleus is to be described by a gaussian, then the "$1/e$ energy" is about 25 Mev. The mesonic level shift contribution associated with the absorption[2] can be estimated with this momentum distribution and is found to be about one-quarter of the level shift arising from the elastic s-wave interaction.[4]

* Supported in part by a grant from the National Science Foundation.
† Paper placed in this experimental session at the authors' request.
[1] E. Henley and M. Ruderman, Phys. Rev. **90**, 719 (1953).
[2] K. A. Brueckner, Phys. Rev. **98**, 769 (1955).
[3] M. Stearns and M. B. Stearns, Phys. Rev. **103**, 1534 (1956).
[4] Deser, Goldberger, Baumann, and Thirring, Phys. Rev. **96**, 774 (1954).

B5. Energy Spectrum of π^+ Meson Production by Cosmic Radiation on Emulsion Nuclei. H. YAGODA, *National Institutes of Health.*—An analysis of 956 π mesons ejected from stars and terminating their range in G5 emulsions exposed in the stratosphere provides a measure of the differential pion energy production spectrum over an interval of 1 to 45 Mev. After applying geometric escape corrections for mesons escaping through the faces and edges of the 1500-micron-thick pellicles, the absolute meson production rate is observed to increase from 0.0025 π^+ particles star^{-1} Mev^{-1} at 1 Mev to a maximum of 0.010 ± 0.002 particles star^{-1} Mev^{-1} at about 20 Mev. This low-energy spectrum fits well with the Bristol[1] data in the region of 30 to 1000 Mev as evaluated from grain density-scattering measurements on shower particles. A similar analysis based on 78 ejected mesons recorded in emulsions exposed on Mt. Evans (4300 meters) indicates that the differential energy spectrum has the same form as in the stratosphere for pion kinetic energies $\lesssim 20$ Mev. The chief difference between the two spectra resides in the magnitude of the integral π^-/π^+ ratio which is 5.2 ± 0.4 at 30 km and 13.7 ± 5.6 at mountain elevations.

[1] Camerini, Lock, and Perkins, *Progress in Cosmic Ray Physics* (Amsterdam, 1952), Vol. I, p. 24.

B6. Angular Distribution of Positive Photo-Pions from Hydrogen. RICHARD D. MILLER AND RAPHAEL LITTAUER,* *General Electric Laboratory.*—Bremsstrahlung from the General Electric 300-Mev nonferromagnetic electron synchrotron was incident in a styrofoam liquid hydrogen target. Emerging positive pions were analyzed by a double focusing magnet and detected in a counter telescope. At angles in the forward hemisphere, a short x-ray beam pulse (0.6 microsecond) and delayed counting of electrons from $\mu^+\rightarrow\beta^+$ decay were used to discriminate against electrons of electromagnetic origin. At backward angles and in the overlap region (to 45° center of mass) direct counting of pions was possible. At each angle the magnet current was adjusted to select the pion energy corresponding to a mean gamma-ray energy of 215 Mev. Measurements were made at eleven angles from 0° to 165° in the center-of-mass system with counting errors of about 3%. These measurements will be described and the relative cross section values presented.

* Now at Cornell University.

B7. Photoproduction of Neutral Mesons from Carbon near Threshold.* J. E. LEISS, *National Bureau of Standards.*—Neutral mesons photoproduced in carbon have been detected by counting the two decay gamma rays in coincidence. The gamma-ray counters were placed 90° to the x-ray beam, each telescope subtending about 0.6 steradian at the carbon target. The mean correlation angle between the two gamma-ray counters was 150°. The efficiency of π^0 detection was calculated using the NBS digital computer and Monte Carlo techniques. The number of π^0s detected was measured as a function of the peak bremsstrahlung energy from the energetic threshold to about 170 Mev. The experimental results can be explained by assuming that all nucleons in the C^{12} nucleus produce p-wave mesons elastically (i.e., the carbon nucleus recoils as a whole in its ground state) according to the theory of Chew[1] and that the production form factor is that of a nucleus whose size and nucleon density distribution is given by electron scattering experiments.[2] The results are sensitive to the assumed size of the nucleus.

* Supported in part by the U. S. Atomic Energy Commission.
[1] G. F. Chew, Phys. Rev. **95**, 1669 (1954).
[2] Jerome H. Fregeau, Phys. Rev. **104**, 225 (1956).

B8. Lifetime of the Neutral Pion.* J. OREAR, G. HARRIS, AND S. TAYLOR, *Columbia University.*—A new upper limit on the π^0 lifetime has been obtained by using 12 $K_{\pi 2}{}^+$ endings in nuclear emulsion where the π^0 decays by a direct pair, $\pi^0\rightarrow(e^+ + e^-)+\gamma$. The distance traveled by the π^0 before decay was measured from the intersection of the K^+ and π^+ tracks to the π^0-pair intersection. The π^0 is emitted in the direction opposite to the observed π^+ track with a velocity $\beta=0.835$. Preliminary measurements give a value $+0.02\pm0.16$ micron for the mean decay distance. The standard deviation of the measurement for each event was ~0.5 micron as determined by measurements on τ^+ secondaries. The π^0 lifetime corresponding to one standard deviation above the mean is 3.9×10^{-16} sec. The likelihood function is down by a factor of 30 for a π^0 lifetime of 1×10^{-15} sec and is rapidly decreasing for longer lifetimes. Thus the π^0 lifetime is most likely less than 1×10^{-15} sec. We are grateful to the nuclear emulsion groups at Rochester, Berkeley, and MIT for supplying us with 6 of the events used.

* Work supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission and by a National Science Foundation research grant.

B9. Elastic Scattering of π^- Mesons by Nuclei.* WINSLOW F. BAKER AND JAMES RAINWATER, *Columbia University,* AND ROSS E. WILLIAMS, *Paul Rosenberg Associates.*—A new π^- meson detector has been developed for use in our measurements of the elastic scattering of π^- mesons by nuclei. It gives greatly improved discrimination against low energy-loss inelastic events. A "transmission" scatterer orientation is used to maintain energy resolution, so only less than 120° scattering is studied. The new results for aluminum and copper agree with the previously reported[1,2] results at small angles but are approximately 2 to 10 times smaller at larger angles, with indications of diffraction structure. Including the incident-beam energy spread, the detector sensitivity is down by factors of 3 and 9 for $E\pm4.5$ Mev and $E\pm9$ Mev when peaked for mean energy E. This is favorable for separating the scattering from carbon into elastic and inelastic components for excitation of the 4.43- and the (7.65 and 9.61)-Mev levels. This has been studied. The elastic scattering is <4 mb/steradian for angles greater than 65°. Detailed results will be presented.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Pevsner, Rainwater, Williams, and Lindenbaum, Phys. Rev. **100**, 1419 (1955).
[2] Williams, Baker, and Rainwater (NEVIS #24), Phys. Rev. **104**, 1695 (1956).

B10. Bubble Density in a Propane Bubble Chamber.* WILLIAM WILLIS† AND EARLE C. FOWLER, *Yale University,* AND DAVID C. RAHM, *Brookhaven National Laboratory.*—Measurement of the number of bubbles per centimeter observed in a propane bubble chamber as a function of particle velocity, at various temperatures, has been reported.[1] These measurements do not give the number of bubbles originally

formed, which may be twice the direct count, because of effects of bubble coalescence and finite optical resolution. These measurements should therefore be considered as an empirical calibration for a particular chamber. The same pictures have been analyzed by a technique which is insensitive to these effects. The bubble coordinates are measured and the distribution of bubble spacings formed. If the bubbles are distributed randomly, this distribution should show an exponential decrease with spacing; actually, a cutoff at small spacings is seen. The distribution at large spacings gives a good estimate of the number of bubbles originally formed. The bubble density determined in this way, as a function of temperature and particle velocity, will be presented and the implications concerning the bubble formation mechanism discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow.
[1] Glaser, Rahm, and Dodd, Phys. Rev. **102**, 1653 (1956).

B11. Piston Operated Liquid Hydrogen Bubble Chamber.* R. K. ADAIR AND L. B. LEIPUNER, *Brookhaven National Laboratory.*—A liquid hydrogen bubble chamber 6 in. long, 3 in. wide, and 2 in. deep has been successfully operated for about nine months. The chamber body, fabricated of electrolytic copper, is connected to a reservoir of liquid hydrogen through heavy copper heat leaks to insure close thermal coupling between reservoir and chamber. A manostat, which controls the vapor pressure over the reservoir, determines and holds constant the temperature of the chamber. Expansion and recompression of the chamber is effected by motion of a piston which works directly on the liquid hydrogen. Good bubble formation occurs with an expansion ratio of about 1.8% in volume. Since no extraneous heat is introduced to control the temperature, and since the expansion-compression cycle is thermodynamically efficient, the chamber used only about 1 liter of liquid hydrogen per hour, when running at a 3.5-sec repetition rate. A stereo camera takes two pictures at an included angle of 20°, using dark-field photography.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

B12. Strange Particle Production by π^- Mesons in a Hydrogen Bubble Chamber.* L. B. LEIPUNER AND R. K. ADAIR, *Brookhaven National Laboratory,* AND W. F. HORNYAK, *University of Maryland.*—The bubble chamber described elsewhere[1] was placed in a 950-Mev π^- beam from the Brookhaven Cosmotron in order to study the reactions $\pi^-+p \rightarrow \Lambda_0+\vartheta_0$ and $\pi^-+p \rightarrow \Sigma+K$. A primary purpose of the experiment is to determine information relating to the spins of the Λ_0 and Σ hyperons by the analysis of the angular distribution of the decay products[2] and the correlations between planes of production and decay planes[3] near threshold. The first 7000 pictures, which were scanned in about 70 hr, contained 13 production events. Although the π^--meson incident energy is about 200 Mev above the $\Lambda_0-\vartheta_0$ threshold and only about 80 Mev above the $\Sigma-K$ threshold, seven of the thirteen events were examples of $\Sigma-K$ production and but six were $\Lambda_0-\vartheta$ events.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.
[1] R. K. Adair and L. B. Leipuner, Bull. Am. Phys. Soc. Series II, **2**, 7 (1957).
[2] R. K. Adair, Phys. Rev. **100**, 1540 (1955).
[3] S. B. Treiman and H. W. Wyld, Jr., Phys. Rev. **100**, 819 (1955).

WEDNESDAY MORNING AT 9:30

Panel Room

(R. M. BOZORTH presiding)

Magnetism, I

BA1. Mechanical and Thermal Limitations to the Production of High Magnetic Fields. H. P. FURTH,* *University of California, Livermore,* M. A. LEVINE, *Cambridge Air Force Research Center,* AND R. W. WANIEK, *Harvard University.*—The principle of generating high transient magnetic fields in massive single-layer coils[1] relies on, and is limited by, the equivalence of magnetic pressures up to a megagauss to the mechanical strengths of metals which range up to 5.10^5 psi. The heat density produced in single-layer coils (of optimum geometry) is likewise an intrinsic property of the magnetic pulse, and field strengths requisite to effect melting and deformation are found comparable under these conditions. Analysis of simultaneous electromagnetic and thermal diffusion leads to the possibility of local thermal instabilities. Experimental observations of such instabilities ("magnetic saw effect"), as well as of mechanical instabilities in metals molten by magnetic fields up to 1.6 megagauss, will be shown.[2] The practicality of force-free and partially force-free geometries for multiple layer coils, as means of attaining much higher magnetic fields, will be discussed.

* One of the authors (H.P.F.) was partially supported by the U. S. Atomic Energy Commission.
[1] H. P. Furth and R. W. Waniek, Rev. Sci. Instr. **27**, 195 (1956).
[2] Levine, Furth, and Waniek, Bull. Am. Phys. Soc. **4**, 191 (1956).

BA2. Improved Inductance Method for Measuring Susceptibilities of Small Paramagnetic Specimens at Low Temperatures. W. P. WOLF* AND F. R. MCKIM, *Clarendon Laboratory, Oxford* (introduced by C. L. Hogan).—An apparatus will be described with which the susceptibilities of small paramagnetic specimens can be determined at temperatures between 77 and 1.8°K. The measurements are made in terms of the change of mutual inductance produced by moving a specimen inside a coil system, using a Hartshorn bridge operating at 175 cps to measure the inductance. The chief advantage of this type of apparatus is its simplicity of operation, since it involves no delicate moving parts. The sensitivity and reproducibility of the appratus have been investigated using a specimen of manganous ammonium sulfate, and it was found that susceptibilities of the order of 3×10^{-6} could be measured to an accuracy of 1%. Some typical results will be presented and sources of error discussed.

* Now at Harvard University.

BA3. Magnetic Susceptibility of Cu–Ni and Ag–Pd from 2.4°K to 295°K. E. W. PUGH, *Carnegie Institute of Technology* (introduced by J. E. Goldman).—The magnetic susceptibilities of Cu–Ni and Ag–Pd alloys in the Cu and Ag rich ranges have been measured between 2.4°K and 295°K by the Gouy method. The room temperature susceptibilities of the Ag–Pd alloys exhibit little change with varying Pd content as has been previously observed.[1] The present measurements further indicate that this susceptibility is almost temperature independent up to 10% Pd in Ag. In contrast to these results, small additions of Ni to Cu give a large paramagnetic contribution at room temperature. While the temperature dependence of the Cu–Ni alloys is considerably smaller than previously reported,[2] it is quite large compared to that of Ag–Pd; and for Ni concentrations greater than 2% a Curie-

Weiss term dominates the total susceptibility at low temperatures. These measurements will be discussed in light of existing localized state and band models.

[1] B. Svensson, Ann. Physik **14**, 699 (1932).
[2] A. R. Kaufmann and C. Starr, Phys. Rev. **63**, 445 (1943).

BA4. Theory of the Magnetic Susceptibility of Oxygen in a Clathrate Compound. J. H. VAN VLECK AND MARY O'BRIEN, *Radcliffe College.*—The oxygen molecules dissolved in a clathrate compound of β-quinol are trapped in rather large holes, separated from each other by about 8 A. Hence the susceptibility should be similar in the main to that calculated for free oxygen molecules. Cooke and collaborators[1] find, however, that their measured values do not agree at helium temperatures with those computed on this basis. In particular, $O^{16}O^{16}$ and $O^{16}O^{18}$ have equal susceptibilities even in this region, whereas theoretically there should be a perceptible difference because of different statistics in the distribution of rotational states. In the present paper it is shown that the experimental results can be fitted, including the similar behavior of $O^{16}O^{16}$ and $O^{16}O^{18}$, if it is assumed that the oxygen molecules in the clathrate compound are exposed to an axially symmetric potential $A(1-\cos 2\theta)$ with a "turning-over" potential $2A = 50\ \mathrm{cm}^{-1}$.

[1] Cooke, Meyer, Wolf, Evans, and Richards, Proc. Roy. Soc. (London) **A225**, 112 (1954).

BA5. Exchange and Superexchange Coupling between Conduction Electrons and *d* Electrons in Magnetic Materials.* G. W. PRATT, JR., *Lincoln Laboratory.*— An analysis has been made of the magnetization of the conduction electrons in a ferromagnetic material induced by their exchange interaction with the *d* electrons. The problem is set up using the density matrix and treated for $T \ll T_C$ and $T \sim T_C$. Results for Fe have been calculated using the nearly free electron and cellular methods. The effect of correlation is taken into account by the Bohm and Pines technique. A magnetization of about 0.15 μ_0 per atom is found. An antiferromagnetic coupling is found to be possible between magnetic ions in dilute magnetic alloys such has been found experimentally in Cu−Mn.[1] The mechanism is a superexchange coupling of the magnetic ions through the conduction electrons. A molecular field theory has been worked out for this case on the basis of an antiferromagnetic coupling between the magnetic ions and a ferromagnetic coupling between the conduction electrons and the magnetic ions.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with the Massachusetts Institute of Technology.
[1] Owen, Browne, Knight, and Kittel, Phys. Rev. **102**, 1501 (1956).

BA6. On the Width of Domain Walls in Small Multidomain Particles.* HENRI AMAR, *Franklin Institute.*—In the evaluation of the width of domain walls in ferromagnetic materials, the only energies ordinarily taken into account[1,2] are the exchange and anisotropy energies. The magnetostatic energy is generally considered as negligible on the assumption that the area of the walls and the size of the domain are much larger than the width of the wall. This assumption is no longer correct for thin films and very small particles, as has been pointed out by Néel.[3,4] A two-domain particle in the form of a parallelopiped is here considered, and the magnetostatic energy is included in the energy density. Using an approximation similar to that of Néel, an expression for the total energy per unit area of wall is found and minimized. It yields widths substantially smaller and energies higher than the corresponding values in bulk material.

* This work was supported by The Franklin Institute Laboratories for Research and Development.
[1] C. Kittel, Revs. Modern Phys. **21**, 4 (1949).
[2] L. Néel, Cahiers phys. **25**, 1–20 (1944).
[3] L. Néel, J. phys. radium **17**, 250 (1956).
[4] L. Néel, Compt. rend. **241**, 533 (1955).

BA7. Phenomenological Theory of the Magnetization Field.* T. L. GILBERT,† *Armour Research Foundation.*—The instantaneous effective field, $\mathfrak{H}(\mathbf{r})$, acting on the magnetization field, $\mathbf{M}(\mathbf{r})$, of an isolated spin system can be shown to be the negative functional derivative, $\mathfrak{H}(\mathbf{r}) = -\delta U/\delta \mathbf{M}(\mathbf{r})$, of the domain energy, $U[M]$.[1] The effect of coupling to surrounding fields (the strain field of the lattice, the densities of diffusing particles at nonequivalent sites, etc.) can be taken into account by replacing the domain energy with a generalized free energy functional of the magnetization fields and the coupled fields. If the coupled fields approach their equilibrium values exponentially, the damping of the magnetization field in the almost adiabatic limit can be characterized by a dyadic function in the most general case, or a single constant in the special case of local isotropic coupling. The motion of the magnetization field can then be described without reference to the motion of the coupled fields. This phenomenological theory leads to a rigorous integral of the motion which is useful for deriving the general equation of motion for a domain wall, including inertial, damping, and strain effects.

* Supported in part by the Department of Defense.
† Present address: Argonne National Laboratory.
[1] T. L. Gilbert, Phys. Rev. **100**, 1243(A) (1955).

BA8. Thin Ferromagnetic Films with Body-Centered and Face-Centered Structures.* SOLOMON J. GLASS AND MARTIN J. KLEIN, *Case Institute of Technology.*—Klein and Smith[1] applied spin wave theory to thin ferromagnetic films with simple cubic structure. They obtained an expression for the total magnetic moment as a function of the temperature and thickness. In this paper the theory is extended to the body-centered and face-centered lattices. Curves are plotted showing the dependence of magnetic moment on reduced temperature and thickness for films with body- and face-centered structures.

* Work supported partly by the ONR.
[1] M. J. Klein and R. S. Smith, Phys. Rev. **81**, 378 (1951).

BA9. Criterion for Ferromagnetism from Observations of Magnetic Isotherms.* A. ARROTT, *Ford Motor Company and Carnegie Institute of Technology* (introduced by J. E. Goldman).—A sufficient condition for ferromagnetism is the appearance of hysteresis in a magnetization *vs* field measurement with the observance of a remanence and a coercive field. However, if with increasing temperature the anisotropy goes to zero before the Curie temperature is reached, the hysteresis should disappear while the material should still be classified as ferromagnetic. Hysteresis is clearly not a necessary condition for ferromagnetism. A necessary condition is that a finite magnetization be observed in zero internal field. To find the Curie point, then, it is necessary to make measurements in smaller and smaller fields as the Curie point is approached.[1] In general, experimenters have not carried out magnetization measurements in such low fields,[2] and in view of the large amount of data in the literature at high fields it would be of value to have a criterion based on the higher field data. The method of Weiss and Forrer of using lines of constant magnetization on a plot of field *vs* temperature involves a large number of isotherms. A criterion is proposed which can be applied to a single isotherm. The criterion is based on the statement that at the Curie point the third power of the magnetization must be proportional to the internal field. The argument will be given for a specific model and then generalized to show that it is independent of the model.

* Supported by U. S. Signal Corps.
[1] D. O. Smith, Phys. Rev. **102**, 959 (1956).
[2] Weiss and Forrer, Ann. phys. **5**, 153 (1926). Kaufman, Pan, and Clark, Revs. Modern Phys. **17**, 87 (1945).

BA10. Coercive Force of Some Iron Oxide Powders at Low Temperatures. A. H. MORRISH, L. A. K. WATT, AND S. P. YU, *University of Minnesota.*—The coercive force of some magnetite and gamma ferric oxide micropowders has been meas-

ured in the temperature range from 77° to 300°K. The mean particle size of four magnetite powders was 1.5 μ for the finest powder and 50 μ for the coarsest. All of the particles were multidomained. The coercive force of these powders had a minimum at 132±2°K, about the temperature at which the first anisotropy constant K_1 becomes zero. The Bloch wall thickness, which depends inversely on $\sqrt{K_1}$, will reach a maximum at $K_1=0$ and will thus give rise to a minimum in the coercive force. Further, the coercive force changed rapidly in the region of the phase transition (113–118°K), increasing by a factor of 2 to 4 as the temperature decreased. In addition, an unusual memory effect was observed. If a sample was put into some state of magnetization below the transition point, warmed to room temperature, and then recooled, the measured value of the coercive force depended on this original state. For a gamma ferric oxide powder, containing multidomain particles, the coercive force decreased almost linearly as the temperature increased. This work is now being extended to single-domain particle powders.

BA11. Coercive Force of Ferromagnetic Particles of Nearly Critical Size. WILLIAM FULLER BROWN, JR., *Minnesota Mining and Manufacturing Company.*—Consider an elongated particle (regarded as an infinite cylinder of radius b) in a decreasing longitudinal field H_0. The original uniform longitudinal magnetization J_s becomes unstable with respect to an infinitesimal uniform rotation at $-H_0J_s=g+2\pi J_s^2\equiv\lambda_0$, if $b<b_c$; it becomes unstable with respect to an infinitesimal divergenceless deviation at $-H_0J_s=g+Cx^2/b^2\equiv\lambda_1$, if $b>b_c$[1] (g=anisotropy constant, C=exchange energy constant, $x\doteq1.84$, $\lambda_0=\lambda_1$ for $b=b_c$). When $b<b_c$, finite rotations can be handled by the Stoner-Wohlfarth method. When $b>b_c$, rigorous treatment of finite deviations leads to nonlinear partial differential equations and to a stability condition difficult to apply. An approximate calculation suggests that at λ_1 the mean magnetization jumps to a negative value; in that case the coercive force of a dilute powder of identical oriented particles (λ_0/J_s for $b<b_c$) is λ_1/J_s for $b>b_c$. This result agrees approximately with Kondorskii's; it is qualitatively consistent with the observed decrease with increasing b.

[1] W. F. Brown, Jr., Bull. Am. Phys. Soc. Ser. II, 1, 323 (1956).

BA12. Fraction of Total Energy of Magnetic Order and Entropy of Magnetic Order Attained at the Curie Temperature by Antiferromagnetic Salts. ARTHUR PASKIN, *Ordnance Materials Research Office.*—Recent magnetic calculations of Brown and Luttinger based on the Bethe-Peierls-Weiss method of computing magnetic order in ferro- and antiferromagnetic spin configurations are extended to obtain the fraction of the total energy of magnetic order and the fraction of the total entropy of magnetic order realized at the Curie temperature. Calculations are carried out both quantum mechanically and classically. To good approximation both methods give the same results for spin equal or greater than unity. Calculations are also compared with data obtained from further analysis of magnetic specific heat curves obtained by Hofmann, Paskin, Tauer, and Weiss from analysis of the experimental specific heat data of antiferromagnetic salts. The calculated fractional energy is in good agreement with experiment while the calculated fractional entropy is greater than that observed.

BA13. Antiferromagnetic Ordering in UO_2. D. G. HENSHAW AND B. N. BROCKHOUSE, *Chalk River Laboratories.*—Neutron powder diffraction measurements on approximately stoichiometric UO_2 have been made at liquid nitrogen (77°K) and at liquid helium (4.2°K) temperatures. At 77°K only lines expected for the known (CaF_2 type) crystal structure are observed. At 4.2°K additional lines appear which can be indexed as the 100, 110, 210, 211, 300, and 310 lines of the normal cubic unit cell. At 77°K, the diffuse scattering is greater than that at 4.2°K and decreases with increasing angle of scattering in the manner characteristic of magnetic diffuse scattering. The intensities of the lines can be explained on the basis of antiferromagnetic coupling of the moments on uranium atoms in adjacent 200 planes, the moments being oriented in a 111 direction. The magnetic moment per uranium atom is about $2.1\mu_B$ and the magnetic form factor is not greatly different from that found[1] for ferromagnetic UH_3. The 100 peak disappears at a temperature in the vicinity of the specific heat anomaly[2] at 28.5°K. Rough measurements on a nonstoichiometric specimen of composition $UO_{2.11}$ gave the same result with a somewhat lower magnetic moment ($\sim1.7\mu_B$) per uranium atom.

[1] C. G. Shull and M. K. Wilkinson (unpublished). See C. G. Shull and E. O. Wollan, *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. II.
[2] Jones, Gordon, and Long, J. Chem. Phys. 20, 695 (1952).

BA14. Antiferromagnetic Resonance Studies on Cr_2O_3 Crystals. EDWARD S. DAYHOFF, *U. S. Naval Ordnance Laboratory.*—It is found experimentally that the antiferromagnetic resonance absorption intensity observed at constant frequency increases as the temperature rises, merging with the paramagnetic resonance intensity at the Néel point. This temperature dependence is found for both ω_1 and ω_4 branches. We use Keffer and Kittel's notation for the resonance modes.[1] As the sublattice magnetization actually approaches zero when the temperature is raised toward the Néel point, it is not immediately evident that the resonance intensity should increase. The reason is contained in a newly derived expression for the peak absorption susceptibility at arbitrary temperature and magnetic field, an extension of an expression given by Keffer and Kittel. An additional term is present representing a sort of field-induced susceptibility which is able to account satisfactorily for the observed behavior. The ω_4 branch of the resonance, not previously reported in Cr_2O_3,[2] is found to show fairly close agreement with theory in recent 72 KMc measurements. Recent improved data for the anisotropy energy constant K indicate variation with the 1.7 power of calculated sublattice magnetization.

[1] F. Keffer and C. Kittel, Phys. Rev. 85, 329 (1952).
[2] E. S. Dayhoff, Bull. Am. Phys. Soc. Ser. II, 1, 283 (1956).

WEDNESDAY MORNING AT 10:00

North Ballroom

(G. B. COLLINS presiding)

Accelerators

C1. Design Description of Oak Ridge Cyclotron Analogue. R. E. WORSHAM, H. G. BLOSSER, AND R. S. LIVINGSTON, *Oak Ridge National Laboratory.*—The Cyclotron Analogue is a fixed-frequency electron cyclotron being used to evaluate ion behavior and resonance problems encountered at energies up to the first integral resonance, $\nu_r=2$, and to verify many design

calculations being made for a high-current, high-energy proton accelerator for the South. The required magnetic field is produced entirely by air-core coils. The desired radially increasing average field is obtained to 0.1% with a pair of circular windings and a large Helmhotz coil; 21 pairs of smaller circular windings are used for trimming. A four-cycle azimuthally varying field is superimposed by the use of 8 pairs of identical 45-degree sector coils. The use of nonmagnetic construction materials permitted the exact calculation of the coil system with a digital computer. The tolerances specified for the magnetic field required most of the coils to be constructed to an accuracy of 0.001 in. and each of the 29 power supplies to be regulated to about 0.05%. Details of the construction techniques, vacuum system, and radio-frequency system will be shown.

C2. Parameter Calculation Program for Oak Ridge Cyclotron Analogue. H. G. BLOSSER AND G. T. TRAMMEL, *Oak Ridge National Laboratory*, AND H. M. MOSLEY, *Texas Christian University*.—Absence of phase stability in the fixed-frequency cyclotron implies that the total phase drift through the machine must be less than 90 degrees. If the number of turns is large (~1000), this limit on phase drift imposes quite stringent precision requirements on the magnetic field. In addition, ion focusing must be maintained to prevent loss of beam. A method has been developed for specifying conductors and currents which produce a magnetic field satisfying, with high precision, both phase-drift and focusing requirements. Currents and conductors yielding a first approximation to the desired field are obtained from approximate analytic formulas. Equations of motion in this field are then integrated exactly by digital computation to find the orbit properties. Differences between desired and actual orbit properties are fed back into the approximate formulas, and corrections to the initial conductors and currents are obtained. The field defined by the corrected parameters is formed, and the equations of motion are reintegrated. The process is repeated until differences between desired and actual orbit properties are acceptably small. Results obtained by utilization of this method in the design of the Oak Ridge Cyclotron Analogue will be presented.

C3. Some Properties of Flare and Gradient Focusing in Accelerator Guide Fields. A. ROBERTS, *University of Rochester*.—The radial gradient of a guide field, k, may be provided interchangeably by the conventional field index $n=\rho/B\cdot\alpha B/\alpha\rho$, or by a variation $R/\alpha-d\alpha/dR$ in the fraction α of the orbit occupied by the field. The latter effect has recently been investigated in some detail[1] and given the name of flare focusing. Flare focusing allows the design of accelerators and focusing magnets with fields of arbitrary index (including zero, i.e., uniform fields) with any resultant field gradient. Examples will be given. Further study also shows that flare and gradient focusing have different properties for radial focusing when the excitation of alternate sectors is varied. The radial betatron frequency remains unchanged with flare focusing, increases with gradient focusing. This property is convenient for systems (e.g , models) in which the radial frequency is to be varied.

[1] F. Salzman and A. Roberts, University of Rochester report NYO-7676 (unpublished).

C4. Coupling between Betatron and Synchrotron Oscillations in an AG Synchrotron.* EDWIN A. CROSBIE AND LEE C. TENG.—In a previous paper[1] Crosbie and Hamermesh studied the effects of coupling between betatron and synchrotron oscillations for a constant gradient synchrotron using systems of linear difference equations to represent the coupled oscillations. The same technique is here applied to a general AG synchrotron with arbitrary half-sector width-ratio and field gradients. To lowest order terms in the ratio of energy gain per rf cavity to total energy, the results give the well-known uncoupled behaviors of these oscillations. The higher order terms, however, appreciably modify the transition energy and the frequencies and damping of both the betatron and the synchrotron oscillations for certain ranges of machine parameters.

* This work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Crosbie and Hamermesh, Phys. Rev. **98**, 233(A) (1955) and Midwestern Accelerator Conference Report MAC-1 (August, 1954).

C5. Misalignment Experiments and Theory in a Small FFAG Betatron.* C. H. PRUETT, F. T. COLE, L. W. JONES, AND K. M. TERWILLIGER, *Midwestern Universities Research Association*.—A major problem of very high energy alternating gradient and FFAG accelerators is their sensitivity to small misalignments of their component magnets. The effect of such misalignments has been tested in a small FFAG betatron by moving individual magnets radially and vertically and measuring the resultant position of the equilibrium orbit. All the magnets of positive or of negative curvature are moved in a test with the beam probe position held fixed, which is equivalent to measuring the position of the equilibrium orbit at different azimuths with a fixed misalignment. We have calculated the position of the equilibrium orbit in the presence of these misalignments in the linear approximation. The effects of magnet edges were replaced by impulsive lenses. Table I shows the theoretical maximum deviation of the equilibrium orbit per unit magnet displacement as determined in straight sections. The experimental points fall on the theoretical curves to within the accuracy of the measurements.

TABLE I.

	Amplitude per unit magnet displacement
Positive magnet moved radially	1.65
Negative magnet moved radially	0.30
Positive magnet moved vertically	0.81
Negative magnet moved vertically	1.94

* Supported by the National Science Foundation, Office of Naval Research, and U. S. Atomic Energy Commission.

C6. Betatron Oscillation Resonances in a Small FFAG Betatron.* K. M. TERWILLIGER,† L. W. JONES,† AND C. H. PRUETT, *Midwestern Universities Research Association*.—The frequencies of betatron oscillation in the small FFAG betatron may be varied independently. The intensity of accelerated beam has been measured over the range between 2.3 and 3 in ν_r and 1 and 3 in ν_z, the frequencies being determined within 1% accuracy by the rf perturbation technique.[1] The beam is destroyed or attenuated only in regions where the frequencies satisfy a relation of the form $p\nu_r+q\nu_z=m$, with p, q, and m positive integers. In particular, no beam is obtained when $p+q=1$ or 2, as expected in a linear machine with imperfections. The beam is usually affected when $p+q=3$ because of quadratic forces. In this case it is always destroyed when q is even and $m=8$, corresponding to nonlinear instabilities in this 8-sector machine, always attenuated when q is even and $m\neq 8$, due to imperfections, and rarely attenuated when q is odd, because of symmetry about the median plane. There is no effect on the beam where $p+q\geq 4$, or when either p or q is negative, consistent with the theory of nonlinear equations.[2]

* Supported by the National Science Foundation, Office of Naval Research, and U. S. Atomic Energy Commission.

† On leave from the University of Michigan.

[1] Hammer, Pidd, and Terwilliger, Rev. Sci. Instr. **26**, 555 (1955).

[2] For a discussion of this theory see P. H. Sturrock, *Static and Dynamic Electron Optics* (Cambridge University Press, New York, 1955).

C7. Characteristics of a Regenerated Synchrocyclotron Beam.* E. M. HAFNER, J. H. TINLOT, AND R. S. HARDING, *University of Rochester.*—In order to investigate the possibility of improving energy discrimination in double-scattering experiments in the 200-Mev region, measurements have been made on a 240-Mev proton beam that has undergone regenerative deflection. Targets at several azimuths were placed outside the largest normal orbits, and protons and neutrons derived from them were studied outside the cyclotron. Results will be presented in regard to the following: (i) intensities of regenerated beams relative to the normal beam, (ii) energy distributions of elastically scattered regenerated beams, (iii) dependence of mean energy on conditions of regeneration, and (iv) distributions in time of accelerated protons both before and after regeneration. Preliminary data on these properties have indicated that considerable improvement in energy selection can be expected from the proper use of this technique.

* Research supported by the U. S. Atomic Energy Commission.

C8. Nonlinear Resonances in Alternating Gradient Accelerators.* G. PARZEN,† *Midwestern Universities Research Association.*—A method has been developed for treating the nonlinear resonances which occur in the betatron oscillations of the strong focusing alternating gradient type of high-energy accelerator. The method predicts the location of the resonances, calculates the stability limits on the amplitude of the oscillations, and also gives the stability limit orbits. The theory has been compared with numerical calculations for the $\nu_z = \frac{1}{4}N$ resonance and for the $2\nu_x + \nu_z = N$ coupled resonance.

* Supported by the U. S. Atomic Energy Commission.
† On leave from the University of Notre Dame.

C9. A Rapid Beam Ejector for the Cosmotron.* DAVID C. RAHM, *Brookhaven National Laboratory.*—The shortest duration beam normally obtainable from the Cosmotron lasts about 2 milliseconds. Since this time is long for some bubble chambers and for some high field pulsed magnets, a device for rapidly throwing the beam into a target was constructed. A two-turn rectangular coil 165 by 20 cm, the turns separated by 17 cm, is placed in a straight section. The two turns are connected in parallel and pulsed with a condenser bank of 8 μf, using a spark gap for a switch. The resonant frequency is 40 kc and at 25 kv the peak current is 50 000 amps, giving a peak field of about 1100 gauss. This field throws the beam inward onto a target. With 18 kv applied it is possible to throw virtually all the beam onto a target in about 3 μsec. A few percent of the beam continues to come in over a period of several milliseconds. This long tail to the beam is also seen with normal beams. It is also possible to obtain a short-duration external beam. With lower voltages it is possible to make only a fraction of the beam hit the target suddenly. The rest of the beam continues for the remainder of the normal acceleration cycle.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

C10. A Method of Obtaining Intersecting Beams with a Single Accelerator.* TIHIRO OHKAWA AND LAWRENCE W. JONES, *Midwestern Universities Research Association.*—The several suggestions for achieving very high center-of-mass energies with head-on collisions between particles of intersecting beams require two tangent accelerators or one accelerator with storage rings. It is possible, using a modification of the radial sector fixed field alternating gradient accelerator, to have particles of the same mass and charge circulating simultaneously in opposite directions in a single accelerator. The geometry consists of a ring of identical magnets, with the field in successive magnets alternating in sign but of the same magnitude. With the field in each magnet increasing radially as r^k, the equilibrium orbits are scalloped so that they lie in stronger fields in magnets of one sign and hence progress around the accelerator. Some advantages may be realized by spiraling the magnets. Calculations will be summarized which show that, for realistic parameters, the circumference factor (ratio of the radius of the accelerator to the minimum particle radius of curvature) may be five or six. While the large circumference of such a machine is a severe disadvantage, the possibility of many intersecting beam target areas, variability of center-of-mass energy, and the relative design and structural simplicity of this configuration make it an interesting possibility.

* Supported by the National Science Foundation, Office of Naval Research, and U. S. Atomic Energy Commission.

C11. Negative Helium Ion Source.* P. M. WINDHAM,† P. J. JOSEPH, J. A. WEINMAN, AND R. G. HERB, *University of Wisconsin.*—Certain theoretical[1] and experimental[2] papers suggest the existence of a negative helium ion with a lifetime sufficiently long (the order of 10^{-3} sec) for acceleration in common accelerating machines. An attempt has been made to find additional evidence for the existence of such ions utilizing the negative hydrogen ion source essentially as described by Weinman and Cameron.[3] There have been minor modifications on the positive ion source, and an oil diffusion pump has been added to the Evapor-Ion pump in order that the helium admitted to the source could be pumped. The positive helium ions are passed through a converter tube filled with hydrogen gas, and the resulting negative ions are magnetically analyzed. The magnetic spectra indicate a peak which can be attributed to negative helium ions. The yield of these negative ions is about 3.5×10^{-3} μa under the conditions of the experiment. Spectra and yield curves at different flow rates of gas and different converter tube potentials will be shown.

* Supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† At North Texas State College.
[1] E. Holøien and J. Midtal, Proc. Phys. Soc. **68**, 815 (1955).
[2] J. W. Hiby, Ann. Phys. Leipzig, **34**, 473 (1939).
[3] J. A. Weinman and J. R. Cameron, Rev. Sci. Instr. **27**, 288 (1956).

C12. Acceleration of Particles through Imperfection Resonances. M. M. GORDON* AND T. A. WELTON, *Oak Ridge National Laboratory.*—If protons are to be accelerated to relativistic energies without frequency modulation, the two focusing frequencies, ν_x and ν_y, must pass through many resonance lines. Formulas have been derived for the effect on beam dimensions produced by acceleration through the more important of these resonances. In each case the appropriate parameters are the energy gain per turn (δ), in units of the rest energy, the fractional field error of relevant type (ϵ), and the slope of the line followed by the operating point as it crosses the resonance line ($d\nu_y/d\nu_x$). For $\delta = \epsilon = 10^{-3}$, and reasonable values of $d\nu_y/d\nu_x$, no imperfection resonance can cause appreciable beam loss except an integral radial or vertical resonance, which requires a somewhat smaller value of ϵ. A number of orbits have been traced in cyclotrons with $\nu_r \simeq 2$, and the mechanism of beam loss has been elucidated. These results strongly indicate that, by using small spiral, large flutter, and a relatively small value for ν_y, vertical stability can be retained at $\nu_x = 2$ with $\epsilon = 10^{-3}$. In addition, a simple trimming coil can be used to reduce the effective value of ϵ rather simply to lower values.

* Summer research participant, University of Florida.

WEDNESDAY MORNING AT 9:45

Empire Suite

(P. MORRISON presiding)

Theoretical Physics I: Quantum and Relativity Theory

CA1. Tentative Field Equations. V. O. NICOLAI, *University of North Dakota.*—Proposed field equations are relativistically invariant; they are consistent with Newton's laws and with the mass energy equivalence. In a limiting case they reduce to the standard wave equation for waves traveling with the velocity of light.

CA2. General Relativistic Cutoff to Quantum Theory. G. W. STUART, *General Electric Company.**—Divergent fermion self-energies are ascribable to operation of the uncertainty principle, permitting the fermion to emit and reabsorb virtual bosons of arbitrarily high momentum. These self-energies would be finite if commutator brackets for canonical variables vanished at very high momenta (small distances). The possibility of such a vanishing is indicated by observing that the metric tensor multiplies $\hbar$, when the commutator is written in the form covariant under Lorentz transformation. Generalizing to Riemannian space, one notes that vanishing of the metrical components close to a fermion implies that a classical description is valid, and virtual emission of high momenta bosons is suppressed. We illustrate these concepts by treating gravity classically and assume a diagonal metric; the radial and time terms have the form $\pm(1-e^{-\beta r})$, the minus sign applying for g_{00}. Inserting this metric into the gravitational field equation produces the fermion stress-energy tensor. Using a result of Tolman, β is evaluated in terms of the fermions' observed mass and is of order of the inverse Schwarzschild radius. For finite mass the energy density is positive definite.

* Hanford Atomic Products Operation, Richland, Washington. Operated by the General Electric Company for the U. S. Atomic Energy Commission.

CA3. Feynman Quantization of Non-Cartesian Systems. JAMES L. ANDERSON, *Stevens Institute of Technology.*—The Feynman[1] space-time approach to quantum mechanics is applied to non-Cartesian systems, i.e., to systems with Lagrangians of the form $L=\frac{1}{2}G_{ij}(q)\dot{q}^i\dot{q}^j+\Gamma_i(q)\dot{q}^i-V(q)$, where $G_{ij}(q)$ is a nonsingular matrix which, however, may not be transformable into δ_{ij} by an appropriate coordinate transformation. In order to make this application it is first necessary to find $S(q',q;\epsilon)$, the action evaluated along a classical path which leads from the point q in configuration space to the point q' in an infinitesimal time interval ϵ. This is accomplished in two ways: by solving the equations of motion and then evaluating $\int L dt$ and by solving the Hamilton-Jacobi equations; the two methods yield the same result. Following Feynman, the Schrödinger equation was then derived. Aside from the usual terms one would expect to obtain, there appeared a term of the form $\frac{1}{8}R\psi$, where R is the curvature scalar formed from the G_{ij}. It thus appears that the Feynman formalism gives a unique prescription for the ordering of factors in a quantum-mechanical expression when such order is in doubt. In addition to the Schrödinger equation, the commutation relations and the Hamiltonian for the system were derived.

[1] R. P. Feynman, Revs. Modern Phys. **20**, 367 (1948).

CA4. Coordinate Conditions as an Aid to Finding Observables.* ALLEN JANIS AND PETER G. BERGMANN, *Syracuse University.*—Bergmann and Goldberg[1] have shown that in order to obtain a consistent quantum theory it is necessary to formulate the theory in terms of the "true observables," whose commutation relations are given by the generalized Dirac bracket. In the Lagrangian formalism, the problem of finding the true observables is equivalent to the problem of finding the constants of the motion.[2] This program becomes complicated if the Lagrangian is "singular," that is to say that the equations of motion cannot be solved for the highest time derivatives. By the use of coordinate conditions, a singular Lagrangian can be made nonsingular, as, for example, the Fermi Lagrangian for electrodynamics. We show that a group of transformations exists for the Lagrangian thus modified which is isomorphic to the original group of invariant transformations, and whose generators, therefore, permit us to determine the true observables and their commutation brackets.

* Supported by the National Science Foundation.
[1] P. G. Bergmann and I. Goldberg, Phys. Rev. **98**, 531 (1955).
[2] Bergmann, Goldberg, Janis, and Newman, Phys. Rev. **103**, 807 (1956).

CA5. Replacing Constraints by Auxiliary Conditions in Gravitational Theory.* F. J. BELINFANTE AND D. I. CAPLAN, *Purdue University.*—Fermi's alteration of Maxwell's theory, destroying complete gauge invariance while imposing "weakly" the Lorentz condition $\mathcal{C}(t=0)=\partial_0\mathcal{C}(t=0)=0$ with $\mathcal{C}\equiv\partial_\nu[A^\nu(-g)^{\frac{1}{2}}]$, was useful in providing a workable quantum electrodynamics and later helping to find the interaction operator of gauge-independent quantum electrodynamics, "physically quantizing" Maxwell's original theory. Similarly useful should be an alteration of the gauge-invariant, coordinate-invariant, and fourleg-invariant theory of gravitation, electromagnetism, and Dirac electrons, adding to the Lagrangian $-(c^4/32\pi G)(-g)^{-\frac{1}{2}}[\mathcal{C}^\lambda\mathcal{C}_\lambda+\frac{1}{2}(-g)S^{(\mu)(\nu)}S_{(\mu)(\nu)}]-(-g)^{-\frac{1}{2}}\mathcal{C}^2/8\pi$ and at $t=0$ weakly imposing besides $\mathcal{C}=\partial_0\mathcal{C}=0$ the coordinate conditions $\mathcal{C}^\mu=\partial_0\mathcal{C}^\mu=0$ and fourleg conditions $S_{(\mu)(\nu)}=0$, where $\mathcal{C}^\mu\equiv\partial_\nu[g^{\mu\nu}(-g)^{\frac{1}{2}}]$ and $S_{(\mu)(\nu)}\equiv N^\lambda\times[h_{(\mu)\sigma}\partial_\lambda h_{(\nu)}{}^\sigma-h_{(\nu)\sigma}\partial_\lambda h_{(\mu)}{}^\sigma]$, with N^λ a time-like unit vector field. The conditions are conserved. All time derivatives of field variables are expressible in terms of canonical variables. The conditions expressed in canonical variables take the form of the first-class constraints of the completely invariant theory. Quantizing, we take care of the second-class constraints by Dirac's modified Poisson brackets. Thus the conditions become equations determining a canonical transformation by which the fundamental equations of the "physically quantized" theory should be found.

* Supported in part by the National Science Foundation.

CA6. Half-Integer Spin in General Relativity. DAVID FINKELSTEIN, *Stevens Institute of Technology and New York University.*—The space of functions $\psi(g)$ of symmetric tensors $g=(g_{ij})$ contains subspaces of half-integer "spin," i.e., contains regular ψ's transforming by the double-valued representations of the Lorentz group L.[1] However, in general relativity, the tensor g is subjected to the general linear group $GL(4,R)$ at each point of space-time. Thus it is necessary to see whether the aforementioned representations of L can be extended to $GL(4,R)$. It has been shown that they cannot be so extended. We conclude that, in spite of the earlier encouraging result, a purely gravitational theory cannot give rise to states of spin $\frac{1}{2}$ when quantized. It is well known that the requirement

that all quantities be general-covariant (which has been imposed here) is not satisfied by any existing theories of spinors in general relativity, and so it has become customary to suspend this requirement, for instance, by introducing orthogonal *vierbeine*. However, some apparently new types of generally covariant tensors of double-valued transformation law are known, and it was hoped to find such among the $\psi(g)$.

[1] David Finkelstein, Bull. Am. Phys. Soc. Ser. II, 1, 208 (1956).

CA7. Advanced and Retarded Potentials in General Relativity. J. WEBER, *University of Maryland*, AND J. A. WHEELER, *Princeton University*.—When the equations of motion for the two-body problem are obtained from the field equations by the method of Einstein, Infeld, and Hoffman, or modifications thereof, there are some questions concerning the combination of advanced and retarded potentials which should be employed. It is well known that a combination of half-advanced and half-retarded potentials gives no two-body radiation. However, let the two bodies be surrounded at great distances with a large number of other bodies initially at rest. We would like to point out that under these circumstances radiation of energy results theoretically even if the sum of half retarded and half advanced potentials is employed. This is a consequence of the fact that the absorber theory of radiation[1,2] can also be employed in general relativity, if we assume the same causality principles to apply as in electrodynamics.

[1] Wheeler and Feynman, Revs. Modern Phys. **17**, 157 (1945).
[2] Tetrode, Z. Physik **10**, 317 (1922).

CA8. Magnetic Moments in the Bhabha Formalism. ROBERT L. PEASE, *Hughes Aircraft Company*, AND JANE PEASE, *Los Angeles*.—Bhabha[1] has proposed a formalism in which the canonical linear field equation, $(i\beta^\mu\partial_\mu+k)\psi=0$, is satisfied by a certain 20-component field function; in the nonrelativistic limit the system described by the formalism decomposes into two states of different mass, both with positive charge, exhibiting spins of $\frac{3}{2}$ and $\frac{1}{2}$, respectively. The magnetic dipole moments of such a system have been calculated using a recently developed technique.[2] It is found that (in terms of a magneton containing the mass of the state in question), the magnetic moment of the spin $\frac{3}{2}$ state is unity, but that in general the magnetic moment of the spin $\frac{1}{2}$ state differs from unity.

[1] H. J. Bhabha, Phil. Mag. **43**, 33 (1952).
[2] J. Pease and R. L. Pease, Phys. Rev. **104**, 816 (1956).

CA9. Some Aspects of the Covariant Two-Body Problem.* SUSUMU OKUBO, *University of Rochester*, AND DAVID FELDMAN, *Brown University*.—We have studied the bound states of the Bethe-Salpeter equation for the nucleon-antinucleon system, including the ladder and pair annihilation diagrams. For simplicity, nucleons and mesons were taken to be scalar, the latter having rest mass zero. Pair effects enter only in S states, with the bound states corresponding to the poles of the meson propagator D_F'. The B. S. equation is intimately related to the integral equation for the generalized vertex operator Γ; this we have solved, using an integral transform method similar to that of Wick and Cutcosky, under the assumption that the nucleon mass is large compared to the binding energy. After performing a self-energy subtraction, we find the energy eigenvalues as a function of the coupling constant. These have the form given by the usual Bohr formula plus corrections. We shall also discuss the application of similar methods to the nucleon-nucleon scattering problem in the ladder approximation.

* This research was supported, in part, by the U. S. Atomic Energy Commission.

CA10. Quantized Free Dirac Field in Hamilton-Jacobi Formulation. HANS FREISTADT, *Newark College of Engineering*.—With the aid of a "meta-calculus" similar to that employed by Valatin,[1] the quantized free Dirac field is put into a Hamilton-Jacobi formulation, which is interpreted causally, in line with earlier work.[2] By "meta-calculus" is meant the theory of the linear operation $d_+(ax^n)/d_+x=\frac{1}{2}a[1-(-1)^n]x^{n-1}$, called the "meta-derivative." To remove any ambiguity in any sum, each term, which may include transcendental factors, is expanded into a Maclaurin series before the meta-derivative is taken. Anticommutation relations of the form $[p,q]_+=i\hbar$ are then satisfied by the explicit representation $p=i\hbar\partial_+/\partial_+q$. In the Schrödinger equation for the state of the quantized Dirac field, the Hamiltonian operator can then be written as a function of the Dirac field operators ψ and the meta-derivative $\partial_+/\partial_+\psi$, and the state vector Ψ written in the form $\exp(\phi-iS/\hbar)$ to yield a modified Hamilton-Jacobi equation.

[1] J. G. Valatin, Proc. Roy. Soc. (London) **A229**, 221 (1955), followed by a private explanation, which is gratefully acknowledged.
[2] H. Freistadt, Phys. Rev. **102**, 274 (1956).

CA11. Mass Renormalization without Expansion in Classical Electrodynamics.* PETER G. BERGMANN, *Syracuse University*.—In 1955 P. A. M. Dirac and the writer, independently of each other, proposed a reformulation of electrodynamics that would avoid completely the introduction of scalar and longitudinal fields. Neither of these new formulations was Lorentz-covariant, and neither succeeded in completely avoiding divergent terms in the action principle or in energy or linear momentum of the system. The present proposal is Lorentz-covariant and considers the simultaneous presence of a free electromagnetic field and of point charges. A single mass renormalization in the action, which amalgamates the non-Maxwell mass of the point charge with the self-interaction term, leads to a Lorentz-covariant and gauge-invariant action principle, in which the (relativistically) transverse field and the configuration variables of the point charges are the independent degrees of freedom and which is free of divergent terms. With the help of this action principle one can form closed expressions for energy and linear momentum that are also free of infinites. In this formulation the free field is unaffected by the motion of the point charges but does itself appear in the ponderomotive equations.

* Supported by the National Science Foundation.

CA12. Dispersion Relations for the *S*-Matrix. J. S. TOLL, D. Y. WONG,* AND J. M. KNIGHT,† *University of Maryland*.—Dispersion relations for the S matrix for fixed spherically symmetric scatterers of finite extent are derived to illustrate restrictions implied by strict causality on scattering through nonzero angles. The forward scattering of appropriate combinations of point sources and plane waves yields an infinite sequence of causal amplitudes which satisfy conventional dispersion relations. Inverting the relation for these causal amplitudes in terms of the S matrix, one obtains dispersion formulas which give $Im S_m(\omega)$, for each m, in terms of combinations of the $Re S_l(\omega)$'s plus low energy limits of $[S_l(\omega)/\omega^{2l+1}]$ for all $l\geq m$. Hence the real part of the scattering amplitude is determined by its imaginary part plus low-energy limits of $[S_l(\omega)/\omega^{2l+1}]$. If a perturbation expansion method is valid, then low-energy limits determine all phase shifts, or the s wave determines all other phase shifts. The massless scalar field, Maxwell field, Klein-Gordon field, and Dirac field are treated. The equivalent formulation of dispersion relations for the S matrix in terms of the vanishing of commutators is derived and is being applied to Delbrück scattering.

* Frank M. Shu Fellow. Assisted by the National Science Foundation.
† National Science Foundation Predoctoral Fellow.

WEDNESDAY MORNING AT 10:00

Boston-Washington Room

(N. F. RAMSEY presiding)

Special Topics in Nuclear Physics

D1. Neutron-Proton Potential as Determined by Electron Scattering from the Deuteron.* JOHN A. MCINTYRE AND SOBHANA DHAR,† *Stanford University.*—Electrons with energies of 400 and 500 Mev have been scattered from the deuteron. The scattering at the largest angles is a factor of five below that expected from scattering by a deuteron charge distribution. This discrepancy is removed by assuming that the proton in the deuteron has an rms radius[1] of 0.78×10^{-13} cm. There is still some uncertainty in the expected deuteron scattering because of the various possible neutron-proton potentials in the deuteron. The scattering from three types of deuteron has been calculated using deuteron *S*- and *D*-state wave functions and the magnetic moment of the deuteron.[2] One deuteron calculated has a repulsive core neutron-proton potential[3] while the other two deuterons have Yukawa potentials.[4] Comparison with the experimental data shows that agreement can be obtained for all deuteron models because of the uncertainty in the radius of the proton.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission, and by the Office of Scientific Research, Air Research and Development Command.
† Now at Lady Brabourne College, Calcutta, India.
[1] E. E. Chambers and R. Hofstadter, Phys. Rev. **103**, 1454 (1956).
[2] V. Z. Jankus, Phys. Rev. **102**, 1586 (1956).
[3] S. Gartenhaus, Phys. Rev. **100**, 900 (1955).
[4] H. Feshbach and J. Schwinger, Phys. Rev. **84**, 194 (1951).

D2. Electron Scattering from Neighboring Nuclei.* B. HAHN,† R. HOFSTADTER, AND D. G. RAVENHALL, *Stanford University.*—A method for measuring small variations in charge distributions of neighboring nuclei, such as isotopes and isotones, has been developed. The method involves the measurement of the ratio of cross sections of the two nuclei compared. In the region of the diffraction dips, pronounced variations of the ratios occur for different assumed nuclear models. The shape and absolute value of the ratio curve give important information about local density differences. For example, in the region of nickel, a one percent difference in the radial parameter of two isotopes, and no difference in the surface thickness parameter, produces approximately a 20% variation in the cross-section ratio in the angular region of the dip. The isotopes $_{28}Ni_{30}^{58}$ and $_{28}Ni_{32}^{60}$ and the isotones $_{26}Fe_{30}^{56}$ and $_{28}Ni_{30}^{58}$ have been studied experimentally. It may be shown that the two extra neutrons in Ni^{60} affect the closed shell proton structure of Ni.

* This research reported here was supported jointly by the Office of Naval Research and the U. S. Atomic Energy Commission, and by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
† Now at the University of Fribourg, Fribourg, Switzerland.

D3. *F*-Wave in *n*-*p* Scattering at 160 Mev.* S. SPITAL, E. M. HAFNER, AND J. H. TINLOT, *University of Rochester.*—The differential cross section for *n*-*p* scattering at an effective energy of 160 Mev has been measured at center-of-mass angles from 12.5 to 173.7 degrees. The data at small angles were obtained by detection of neutrons scattered by liquid hydrogen; at large angles, the recoil protons from polyethylene were observed. An additional absolute measurement at 30 degrees was made, and the data were analyzed to give a least-squares fit to a polynomial up to and including the term $\cos^6\theta$. The result obtained in this way is statistically admissible, whereas the analogous result for a polynomial going only to $\cos^4\theta$ is not. We therefore have evidence for the appearance of significant *F*-wave contribution to the scattering at this energy. Analysis of an independent experiment[1] in which data were obtained from 50 to 178 degrees indicates excellent agreement throughout the entire region of overlap.

* Research supported by the U. S. Atomic Energy Commission.
[1] Randle, Taylor, and Wood, Proc. Roy. Soc. (London) **A213**, 392 (1952).

D4. Small Angle Elastic *p*-*p* Scattering at 440 Mev.* HENRY HORSTMAN, S. K. KAO, AND GEORGE HINMAN, *Carnegie Institute of Technology.*—Four-hundred and forty-Mev protons from the Carnegie Tech synchro-cyclotron have been scattered from a liquid hydrogen target and the elastic scattering cross section studied in the Coulomb interference region. Nuclear emulsion plates were used as detectors. Two and one-half inches of copper were interposed between the scattered beam and the plates to remove deuterons and low energy protons from the $p+p\rightarrow\pi^++d$ and the $p+p\rightarrow p+n+\pi^+$ reactions. Plate exposures have been made, and scanning is in progress to improve statistics.

* This research was supported by the U. S. Atomic Energy Commission.

D5. Absolute Neutron Spectra from 190-Mev Proton Bombardment of Various Elements. EDWARD E. GROSS, *Oak Ridge National Laboratory.**—Nuclear emulsions were used to measure the differential cross sections for the production of neutrons in the energy interval 0.5 to 12 Mev resulting from 190-Mev proton bombardment of C, Al, Ni, Ag, Au, and U targets. The neutron yields were measured at laboratory angles of 45°, 90°, and 135° to the beam direction. The angular distribution of the neutrons emitted from U, Au, and Ag appears to be isotropic in the laboratory system. An angular variation begins to appear in the neutrons emitted from Ni and becomes more pronounced in the neutrons emitted from Al and C. The observed spectra are consistent with a combination of two processes: (1) an isotropic evaporation process, and (2) an angle-dependent cascade process. The average excitation energies obtained from the data are: U 88±18 Mev, Au 83±17 Mev, Ag 69±12 Mev, Ni 57±9 Mev, Al 50±8 Mev, and C 27±5 Mev. These values are higher than predicted by Monte Carlo calculations.

* Work performed at the University of California, Berkeley.

D6. Proton-Nucleus Elastic Scattering at 40 Mev.* NORTON M. HINTZ, *University of Minnesota.*—The success of the optical model in accounting for nucleon-nucleus elastic scattering justifies further experimental efforts at new energies. An eight-foot-diameter general purpose scattering stand[1] has been constructed for use with the 40-Mev proton beam from the second stage of the Minnesota Linac. The scattering takes place in a 12-in. diam chamber with a 335°-continuous 3-mil mylar window. Two steel arms, for detector and monitor assemblies, can be positioned remotely to ±0.02°. For detecting the scattered protons, a 1-in. diam NaI crystal with a thin entrance window is used. This is coupled, via a 3-in. long Lucite light pipe, to a 2-in. end-windowed photomultiplier. Energy resolution as good as 1½% (full width at half maximum) can be obtained with this arrangement providing heavy shielding and moderately slow counting rates are used to minimize pulse pile up effects. Elastic scattering data will be presented for C, Al, Sn, and Pb, generally from 15° to 150° at 2½° intervals with about ±¾° angular resolution. The data will be analyzed

by A. E. Glassgold's group at Minnesota to extract the shape and strength parameters of the optical model.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Designed in collaboration with Eisberg, Day, and Williams.

D7. Creation of the Heavy Elements by Neutron Capture on a Fast Time Scale.* PETER FONG, *Utica College of Syracuse University and M. I. T.*—The cosmological abundance curve of Suess and Urey[1] shows pronounced peaks at Br, Xe, and Pt just before the peaks at the neutron magic-number nuclides Y, La, and Bi, respectively. An explanation for the formation of the former group of peaks has been suggested by Coryell[2] that these elements were first formed, in large abundance, as neutron-rich unstable nuclei with magic-number neutrons in a neutron capture process on a fast time scale and later changed to Br, Xe, and Pt groups by beta-decay. The mathematical formulation of this problem is represented by about a thousand simultaneous ordinary differential equations. By a transformation this set of equations may be replaced by a single partial differential equation which takes the form of equation of continuity and thus may be solved analogously by determining the stream lines. By postulating a neutron capture mean lifetime for all (nonmagic-number) nuclides of the order of 0.05 sec, the positions, widths, and heights of the abundance peaks may be calculated which agree reasonably well with the observed results.

* This work was supported in part by the U. S. Atomic Energy Commission.
[1] H. E. Suess and H. C. Urey, Rev. Modern Phys. **28**, 53 (1956).
[2] C. D. Coryell (to be published).

D8. Spectral Distribution and Z Dependence of Thick Target Bremsstrahlung. E. A. EDELSACK,* W. E. KREGER, W. MALLET, AND N. E. SCOFIELD, *U. S. Naval Radiological Defense Laboratory.*—Continuing earlier work,[1] thick target spectra of bremsstrahlung radiation for electrons were measured using the USNRDL Van de Graaff generator as the source of monoenergetic electrons. The present measurements are from gold, copper, aluminum, and polystyrene targets at electron energies of 1.00, 1.50, and 2.00 Mev. The target thickness for each element at each energy was equal to the calculated maximum range of the electron, using Spencer's values of residual range.[2] Pulse-height distributions were measured with a well-collimated 4-in. by 4-in. single-crystal 20-channel gamma-ray scintillation spectrometer. All the results are for an 0° angle between the collimator-spectrometer axis and the direction of the incident electrons. The experimentally observed pulse-height distribution was the subject of a series of corrections to obtain the true bremsstrahlung spectrum. These corrections will be discussed. The method of unfolding the spectra due to the response of the NaI crystal and its associated electronics will be presented. Also, the dependence of the bremsstrahlung spectra on the atomic number of the target will be discussed.

* Now with the Office of Naval Research.
[1] E. A. Edelsack and W. E. Kreger, Phys. Rev. **100**, 973(A) (1955).
[2] L. V. Spencer, Phys. Rev. **98**, 1597 (1955).

D9. Differential Energy and Angle Spectra of the Photons Emerging from Thick Slabs Irradiated by a Broad Beam of Co^{60} Gamma-rays. N. E. SCOFIELD, *U. S. Naval Radiological Defense Laboratory.*—Using a "total-absorption" scintillation spectrometer, 120-channel pulse-height distributions were obtained for forward scattering angles of 0°, 3°, 5°, 10°, 15°, 20°, 30°, 45°, and 60° and for slab thicknesses of 0 in., 2 in., 3 in., $4\frac{1}{4}$ in., and $5\frac{1}{4}$ in. of iron and for slab thicknesses of 0 in., 3 in., 6 in., 9 in., 12 in., and 16 in. of aluminum. Some corrected pulse-height distributions are compared with calculated distributions based on only first and second scattered quanta (method of Certaine). A comparison is made between some of the integrated data and the infinite medium theory (as modified by boundary effects) of Spencer, Fano, and Berger.

D10. Range-Energy Measurements in Al for Protons of 2 to 5 Mev.* H. BICHSEL AND B. J. FARMER, *The Rice Institute.*—Few range energy measurements for protons from 2 to 5 Mev are known. The present investigation was started in order to remedy this situation and to investigate the shell corrections which for Al account for about 3% of dE/dx in this energy region. The determination of incident proton energies is done with various (p,n) thresholds in The Rice Institute electrostatic generator. The ranges are measured in the triple coincidence counter developed at Princeton University and previously reported.[1] Results are in agreement with the theoretical curve[1] to better than 1%:

E_p(Mev) =	2.130	3.033	4.017	5.038	± 0.1%
R_{exp}(mg/cm²) =	12.66	22.38	35.68	52.23	± 0.2%
Multiple scattering correction (mg/cm²) =	+0.06	0.09	0.12	0.16	±10%

The experimental determination of multiple scattering gives results about half as big as computed for Al.[1] Measurements on Ni and Ag are in progress.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Bichsel, Mozley, and Aron, Phys. Rev. (to be published); Phys. Rev. **94**, 764(A) (1954).

WEDNESDAY AFTERNOON AT 2:00

Boston-Washington Room

(L. BOLLINGER presiding)

Neutron Physics and General Nuclear Physics

E1. Neutron Activation Cross Sections with Sb-Be Neutrons. N. H. LAZAR, W. S. LYON, AND R. L. MACKLIN, *Oak Ridge National Laboratory.*—Neutron activation cross sections for Sb-Be neutrons (~25 kev) have been measured by gamma-ray scintillation spectrometry. General agreement with theoretical predictions of absorption cross sections *vs* atomic weight is found. Magic shell effects are quite evident and correspond with singularly low observed cross sections. Agreement with earlier published results[1] is generally within a factor of two. The activity determination through the measurement of the gamma-ray intensity rather than the beta rays permits thick samples to be used, and thereby a large increase in sensitivity and precision is obtained in favorable cases; e.g., a cross section of 1.02±0.2 b was found for Na^{23}. Values of 1.08±0 10 mb for Au^{197} and 0.80±0.08 b for In^{115} (54 min.) have been measured. Results on other nuclides are being checked. This work is based on an absolute measurement of the iodine activation cross section reported earlier.[2]

[1] V. Hummel and B. Hammermesh, Phys. Rev. **82**, 67 (1951).
[2] R. L. Macklin, Bull. Am. Phys. Soc. Ser. II, **1**, 264 (1956).

E2. Photo-Neutron Yields in the Rare Earth Region.* BEN PETREE, M. WEISS, AND E. G. FULLER, *National Bureau of Standards.*—The total photo-neutron yield curves for Sn, I, Ce, Sm, Tb, Ho, Er, Yb, Ta, Au, and Pb have been measured for x-ray energies from 7 to 40 Mev with the NBS 50-Mev betatron. The beam was monitored by a transmission ionization chamber, which was calibrated in terms of ergs in the transmitted beam by the crystal spectrometer method.[1] Cross sections for neutron production *versus* x-ray energy were obtained via the Penfold-Leiss Tables.[2] Since multiple neutron production is included, the cross sections should correspond to the total nuclear absorption cross sections only below the $(\gamma,2n)$ threshold. The "giant resonances" of elements with large quadrupole deformations were broader than of those elements with small quadrupole deformations[3]; for example, the full width at half maximum was about 10 Mev for Er and Ho compared to about 6 Mev for Au and Pb and 7 Mev for Sn.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Koch, Leiss, and Pruitt, Bull. Am. Phys. Soc. Ser. II, 1, 199 (1956).
[2] A. S. Penfold and J. E. Leiss, Phys. Rev. 95, 637 (1954).
[3] K. Okamoto, Progr. Theoret. Phys. 15, 75 (1956); M. Danos, Bull. Am. Phys. Soc. Ser. II, 1, 199 (1956).

E3. Radiations Following Neutron Capture in the Separated Isotopes of Europium. J. M. CORK, M. K. BRICE, R. G. HELMER, AND D. E. SARASON, *University of Michigan.*—Neutron capture in normal europium leads to two long-lived radioactive emitters. Because of their similarity, no clear-cut analysis of the decays has been possible. With enriched isotopes, Eu^{151}(92%) and Eu^{153}(95%), the problem is greatly simplified. From each of the very strong Eu^{152} and Eu^{154} sources some forty electron lines are observed in photographic magnetic spectrometers. Both nuclides can possibly decay either by K capture to Sm or by beta emission to Gd. For the lower energies the KLM differences allow a positive identification of the product nuclei. A strong similarity appears between the electron spectrum of Eu^{152} and that of Eu^{154}. Several gamma rays have almost equal energies in the two sources. The decay in every case leads to even-even stable nuclei, and some of the gamma transition energies in kev are: Sm^{152}—122.7, 245.0, 445.2, 875, 1095, 1419; Gd^{152}—104.5, 345.1, 412.2, 782, 1124; Sm^{154}—121.8, 690.6; Gd^{154}—84.2, 123.5, 248.0, 344.3, 723. The beta spectrum of Eu^{152} has components of energies 1456±15, 1044±20, and 684±30 kev, as well as several at lower energy. These isotopes occur where the rotational theory should apply, but the prediction of energy levels deduced from the strong coupling model needs modification.

E4. Rule Concerning Isomeric Ratios Following Slow Neutron Capture. E. DER MATEOSIAN AND M. GOLDHABER, *Brookhaven National Laboratory.*—It has been known for some time that the relative cross sections for radiative neutron capture leading to two isomeric states in a given nucleus are such as to favor the formation of the isomeric level with spin closest to that of the compound nucleus.[1] If we use recent data on spin assignments for isomers[2] and thermal neutron capture cross sections,[3] we find this rule well confirmed with only one exception, Ge^{77}, for which the cross sections given are 0.030 b for the lower spin state (1/2−, 59 sec) and 0.20 b for the higher spin state (7/2+, 12 hr). Assuming the known decay schemes,[4] we have remeasured these cross sections using enriched stable isotopes[5] of Ge and found them to be 0.06±0.01 and 0.05±0.01 b, respectively. Other isomeric ratios are being measured.

* Under auspices of the U. S. Atomic Energy Commission.
[1] E. Segrè and A. C. Helmholz, Revs. Modern Phys. 21, 271 (1949).
[2] M. Goldhaber and R. D. Hill, Revs. Modern Phys. 24, 179–239 (1952).
[3] D. J. Hughes and J. A. Harvey, BNL 325.
[4] Burson, Jordan, and LeBlanc, Phys. Rev. 96, 1555 (1954).
[5] Obtained from the Stable Isotopes Division, Oak Ridge, Tennessee.

E5. A Double Flat Crystal Spectrometer for Neutron Capture γ-Ray Studies. J. W. KNOWLES, *Chalk River Laboratories.*—In this spectrometer a 1½-in.×2-in. diameter beam of well-collimated γ-rays produced by (n,γ) reactions in the sample while positioned in the NRX reactor is Laue reflected from the 211 plane of a cleaved calcite crystal ¾-in. thick. The reflected beam proceeds through a sollar slit and is energy analyzed by being Laue reflected from a second similar calcite crystal which is set in the anti-parallel position. This doubly reflected beam then traverses a further sollar slit and is detected by a NaI scintillator. In preliminary measurements, the γ-rays have been observed from a sample of natural titanium metal. The peak to background ratio for the strong 1.385-Mev γ-ray of Ti^{49} is 20 to 1. The measured reflectivity of a single calcite crystal has been measured and is 40% for 1 Mev and 10% for 1.4-Mev γ-rays. The full width at half maximum intensity of a diffracted γ-ray is 2 sec of arc which corresponds to an energy resolution of 0.4% at 1 Mev. The measured reflectivity of the 211 plane of calcite as a function of energy together with the observed γ-ray line width fits the diffraction theory of a mosaic crystal.

E6. New Delayed Neutron Activity.* G. J. PERLOW AND A. F. STEHNEY, *Argonne National Laboratory.*—A delayed neutron activity which has a half-life of 15.5±1 sec and follows the chemistry of bromine has been found among fission products. It is attributed on the basis of period[1] to Br^{88} and represents a case of neutron emission following the β-decay of an odd-odd precursor. The source was prepared by a gas flow system in which air and Br_2 carrier were passed rapidly through a solution of a fissionable substance undergoing irradiation at the thermal column of CP-5, and the activity was removed from the air stream by bubbling through CCl_4. Additional chemistry was done en route to insure the absence of active iodine. After the air flow was stopped, the decay of neutron activity contained in the CCl_4 was observed by a BF_3 long counter and was resolved into the known 54-sec period of Br^{87} and the 15.5-sec period reported here. Initial counting rates of 500 to 1000 cps were found suitable. When long collection times were used, the ratio of the counting rates of the two activities was $N_{15.5}/N_{54}=0.7$. A run with shorter collection time enhanced the short-lived activity to give $N_{15.5}/N_{54}=2$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. Sugarman, J. Chem. Phys. 17, 11 (1949).

E7. Age of Polonium-Beryllium Neutrons in Various Metal-Water and Metal-Alcohol Lattices.* KALMAN SHURE AND MELVIN REIER, *Westinghouse Electric Corporation.*—The slowing down distribution of Po-Be neutrons to indium resonance and thermal energies has been measured for Al-H_2O, Fe-H_2O, Zr-H_2O, and Al-furfuryl alcohol lattices with metal-to-liquid ratios of 2:1, 1:1, 1:2, and 0.

* Supported in part by the U. S. Bureau of Ships.

E8. Calculation of the Age of Po-Be and Monoenergetic Neutron Sources.* FELIX OBENSHAIN† AND ROBERT L. HELLENS, *Westinghouse Electric Corporation.*—The second moment of the distribution of Po-Be neutrons for various metal-liquid ratios has been calculated from a solution of the neutron transport equation. In addition, the effect of changing the oxygen cross sections has been computed. Comparison will be made with experimental values at 2.3 and 14 Mev and values obtained by a Monte Carlo calculation.

* Supported by the U. S. Atomic Energy Commission.
† Now at the University of Pittsburgh.

E9. Experimental Track Counter for Neutron Film Badges.* K. C. SPEH AND G. W. MORTON, *Airborne Instruments Laboratory, Inc.*—An experimental device has been constructed to count proton tracks in NTA health badge emulsions. The problem is to distinguish very short (three-grain) tracks in the presence of a random grain background. To do this a television type scanner has been constructed, with optics which allow

resolution of individual grains comprising a track. A dark-field image of about 100 times magnification is focused on the face of the vidicon pick-up tube. By use of fused quartz delay lines three consecutive scan lines are continuously compared. Video signals from images which occupy only the middle scan line path are passed to a screening circuit which eliminates those of insufficient duration or continuity. The output from the screening circuit thus corresponds to tracks whose direction in the image plane is within a few degrees of the direction of horizontal scan. Adjustable duration and continuity thresholds and provision of an interlaced field allow flexibility for investigating the optimum track identification criteria. Experimental data are given on the effective acceptance angle and depth of focus. Scanning rates are estimated for the health badge application, and other possible applications are suggested.

* Work supported by U. S. Atomic Energy Commission, Division of Biology and Medicine.

E10. Automatic Recording Time-of-Flight Apparatus for Fission Fragments. J. S. FRASER AND J. C. D. MILTON, *Chalk River Laboratories.*—An apparatus has been built to measure both the velocities of a fission fragment pair. The zero time signal is obtained by focusing with an electrostatic einzel lens the δ rays ejected when one of the fragments passes through a thin gold-coated VYNS foil mounted at 45° to the fragment direction. In traversing the lens the electrons are accelerated to 10 kv and impinge on a 0.015-in. thick plastic phosphor, NE 101, mounted on a RCA 6342 photomultiplier. At the end of the 177-cm flight path the fragments are detected by 4-in. diameter disks of the same phosphor and RCA 6342's. The flight times range from 100 to 250 mμsec and are converted to voltage pulses by controlling the charging of a condenser by a 6BN6 gated beam tube. The amplified voltage pulses are recorded on a 100-channel analyzer whose memory is 5-channel IBM tape. The system has been used as a three-dimensional analyzer by storing pulses representing the two flight times and one additional pulse (in this case that produced by the fission gamma rays in a 4-in.×4-in. diameter NaI crystal) and analyzing them consecutively. The information is later transferred to IBM cards and is then in a convenient form for analysis on IBM accounting equipment. The system has been used successfully with rates of 5 cpm. For appreciably higher rates consideration has been given to feeding the punched tape directly into a high-speed computer.

E11. Tables of Cylinder Activation and Solid Angles Subtended by Circular Apertures and Cylinders.* A. V. MASKET,† *University of North Carolina,* AND R. L. MACKLIN AND H. W. SCHMITT, *Oak Ridge National Laboratory.*—Extensive tables have been computed on the ORACLE at Oak Ridge National Laboratory to six significant figures for the following magnitudes: (a) the solid angle subtended by a circular disk, (b) the solid angle subtended by the lateral surface of a right circular cylinder, (c) the activation of a right circular cylinder by a point source. These quantities are of fundamental importance in all applications of end-window counters, cylindrical counters, and cylindrical radiation detectors. Details of the mathematical representation of the solid angle as a simple contour integral will be presented along with a discussion of errors, checking procedures, and ranges of variables. Each table contains 12 500 or more entries. The tables and a complete discussion will be available in report ORNL-2170.

* Work performed under tha auspices of the U. S. Atomic Energy Commission.
† Research participant at Oak Ridge National Laboratory (summer, 1955).

WEDNESDAY AFTERNOON AT 2:00

Grand Ballroom

(M. H. HEBB presiding)

General Solid-State Physics

EA1. Red Luminescence of CdS Crystals. H. SHENKER, *U. S. Naval Research Laboratory.*—Waibel[1] has recently investigated the red luminescence of CdS and has reported a sharp peak in the excitation spectrum in the vicinity of the absorption edge. The red luminescence ($\lambda > 6500$ A) of CdS crystals, excited by visible light, has now been further studied. The peak in the excitation spectrum occurs at about 5110 A for most crystals, the exact position varying from crystal to crystal due to variations in the relative luminescence efficiency of the surface and the bulk of the crystals. The peak is much sharper and occurs at somewhat shorter wavelengths than the corresponding peak in the photoconductivity curve. The intensity of the red luminescence is found to vary as the first power of the exciting light for highly conducting crystals and as the 1.5 to 2.0 power for photoconductive crystals. Highly insulating crystals show very little red luminescence. The application of infrared ($>1.0\,\mu$) sufficient to quench 95% of the photoconductivity is found to have no measurable effect upon either the intensity or the time constant of the red luminescence.

[1] E. Waibel, Ann. Physik [6] 17, 389 (1956).

EA2. Photoelectric Emission from *F* Centers in KI Single Crystals. H. R. PHILIPP AND E. A. TAFT, *General Electric Research Laboratory.*—External photoelectric emission from cleaved single crystals of KI containing *F* centers is compared to previous results on evaporated films.[1] The centers were formed by irradiation in the first fundamental absorption band of the salt. Yields due to direct ionization of *F* centers are about 10^{-6} electrons/incident photon, only 10 times lower than for films. Exciton-induced emission shows a peak value 5×10^{-5}, about 4 times lower than for films. Except for these relatively small differences in yield, the results for crystals and films are alike. One estimates that the irradiation produced *F*-center densities in excess of 10^{18} cm^{-3} near the single crystal surface. While the ratio exciton-induced to direct ionization is slightly higher in crystals than in films, the effective cross section for exciton-induced ionization is still $<10^{-14}$ cm^2; thus, the photoemission provides direct evidence for energy transfer from excitons but not necessarily for migration.

[1] L. Apker and E. A. Taft, Phys. Rev. 79, 964 (1950).

EA3. Transport of Copper in Silicon. C. J. GALLAGHER, *General Electric Research Laboratory.*—The high temperature transport of copper in silicon has been measured using Cu^{64}. Planar geometry was used, with a constant source on one face and a gold alloy sink on the other. The product of the solubility and diffusion constant was found to be 1.2×10^{13}

$(cm/sec)^{-1}$ at 1130°C. Fuller *et al.*[1] give $D=3\times10^{-8}$ cm²/sec at 900°C with very small temperature dependence, so that there are at least 2×10^{17} cm^{-3} copper atoms with the high diffusion coefficient. Thurmond and Struthers[2] give 5×10^{17} cm^{-3} for the solubility at 1100°C, so that at least 40% of the copper must have this high diffusion coefficient. It has also been determined by application of an electric field that the transport of rapidly moving copper is enhanced along the field and retarded against the field. Comparison of experimental and theoretical values of the transport shows that the fast-moving copper carries a single positive charge. This is consistent with the idea that the rapidly diffusing copper is interstitial.

[1] Fuller, Struthers, Ditzenberger, and Wolfstirn, Phys. Rev. **93**, 1182 (1954).
[2] C. D. Thurmond and J. D. Struthers, J. Phys. Chem. **57**, 831 (1953).

EA4. Relativistic Kronig Penny Model.* R. D. Woods and J. Callaway, *University of Miami.*—A one-dimensional model of a crystal has been studied using the Dirac equation. The energy bands for a Kronig Penney potential and a delta function potential have been found. The transcendental equation relating energy to wave number has the same form as in the nonrelativistic case. The difference is only in the dependence of the coefficient and arguments on energy, which is characteristic of the Dirac equation. In the usual limit of infinitesimal width and infinite height, the square-well potential gives a result different from the delta function case. In the limit of relativistic energies the square-well potential gives the free electron energy dependence, linear in wave numbers. The delta function potential in this limit, however, gives a periodic energy band structure with all bands the same width and all gaps the same width and with an energy dependence near the gaps quadratic in the wave number. As the strength of the delta function decreases the free electron energy dependence is obtained.

* Supported by the Office of Naval Research.

EA5. Elastic Constants of LiF from 4.2°K to 300°K by Ultrasonic Pulse Methods. C. V. Briscoe* and C. F. Squire, *The Rice Institute.*—The values of the elastic constants of lithium fluoride at room temperature are: $C_{11}=10.97\times10^{11}$, $C_{12}=4.40\times10^{11}$, and $C_{44}=6.30\times10^{11}$ d/cm². These agree with those reported by Huntington and Bergmann provided the work of Huntington is corrected by using the proper value of 2.601 g/cm³ for the density. At 4.2°K our new values are: $C_{11}=12.39\times10^{11}$, $C_{12}=3.60\times10^{11}$, and $C_{44}=6.46\times10^{11}$ d/cm². From these elastic constants we compute the compressibility at room temperature to be: $K=1.518\times10^{-12}$ cm²/d (in good agreement with Slater's measurements). Using the values of the longitudinal and transverse wave velocities the Debye characteristic temperature is calculated to be: $\theta_D=775$°K at 4.2°K (in fair agreement with Martin's value taken from specific heat work[1]) and $\theta_D=779$°K at 300°K. On the other hand, the θ_D *vs* T required to make a simple Debye theory fit the experiments of Clusius *et al.*[2] varies by a large amount between 20°K and 300°K. We can get a good fit to the specific heat experiments over a large range by using a combination of Debye theory for $N/2$ fluorine oscillators and an Einstein theory for the other $N/2$ lithium oscillators. This research was supported by the Robert Welch Foundation.

* Magnolia Petroleum Company Fellow in Physics.
[1] D. L. Martin, Phil. Mag. **46**, 751 (1955).
[2] K. Clusius *et al.*, Z. Naturforsch **4A**, 424 (1949).

EA6. Anisotropic Anelasticity in α Quartz.* John H. Wasilik, *National Bureau of Standards* (introduced by Martin Greenspan).—An anisotropic relaxation peak has been observed in the internal friction of crystalline quartz. The height of the loss peak increases by a factor of 2.1 between a sample stressed in the Y direction and one stressed in a direction −18.5° from the Y axis. The shape of the observed relaxation peaks can be fitted by simple relaxation theory using an activation energy of 24 kcal/mole and a relaxation time of 0.6×10^{-14} sec. A possible mechanism for the loss is the relaxation of stress-induced preferred distribution of impurities similar to that observed by Snoek[1] in alpha iron. The possibility that this relaxation peak and one observed by Cook and Breckenridge[2] are due to lithium is discussed.

* Supported in part by U. S. Office of Naval Research.
[1] J. L. Snoek, Physica **8**, 711 and 734 (1941).
[2] R. K. Cook and R. G. Breckenridge, Phys. Rev. **92**, 1419 (1953).

EA7. Radiation Effect of Positive Ion Bombardment on Quartz and Vitreous Silica. R. L. Hines, *Ford Motor Company.*—Samples of quartz and vitreous silica have been bombarded by 30 to 50 kev A^+ and N_2^+ ions, and the nature of the bombarded region has been investigated by measuring the reflection coefficient as a function of the wavelength of the incident light from $\lambda=713$ mμ to $\lambda=384$ mμ. The results are consistent with the picture of a layer ~0.1 μ deep, whose depth is determined by the incident ion type and energy, and with a refractive index depending on the integrated ion flux. For quartz, the ordinary refractive index for $\lambda=384$ mμ is decreased from the initial value of 1.559 to a saturation value of 1.497 by 10^{18} ions/cm² (37-kev A^+ ions). Similar bombardment of vitreous silica increases its refractive index to a value close to the saturation value of bombarded quartz. Both A^+ and N_2^+ ions produce the same changes in refractive index. Data on annealing experiments will be presented and compared with the annealing of other radiation effects in quartz. The relative importance of displacements and displacement spikes in producing the changes in refractive index will be discussed.

EA8. Viscosity of the Electron Gas in Metals. M. S. Steinberg, *Stevens Institute of Technology.*—Using an adaptation of the variational principle for the problem of electrical resistivity, the viscosity of the electron gas in normal metals is computed for a constant velocity gradient. The temperature dependence of the viscosity is found to be somewhat more complicated than that of the electrical resistivity. The effect of a magnetic field is calculated when a time of relaxation exists. The effects of sinusoidal velocity gradient and finite sample size are considered. Application to ultrasonic attenuation in normal metals at low temperatures is discussed.

EA9. Calculation of the Short-Range Correlation Energy in the Bohm-Pines Theory. J. G. Fletcher* and D. C. Larson,* *Princeton University.*—The contribution to the one-electron energy in metals produced by the short-range correlations of electrons of antiparallel spin has been calculated according to the theory of Bohm and Pines[1] using second-order perturbation theory. The effect of this contribution on the density of states, x-ray band width, specific heat, and conductivity has been obtained. Comparison with experimental values will be made.

* National Science Foundation Pre-Doctoral Fellows.
[1] D. Pines in *Solid State Physics* (Academic Press, Inc., New York, 1956), Vol. I.

EA10. Width and Shift of Spectral Lines Due to Dissipative Interactions. R. Brout, *Cornell University.*—Associated with a macroscopic state (say specified, e.g., by the populations of phonons of given **k** in a slightly anharmonic crystal) there is a lifetime Γ^{-1} resulting from "collision" type or dissipative interactions. Γ is the width of the macroscopic state. It is large, of the order of Avogadro's number. If the crystal undergoes spontaneous emission losing, say phonon k and emitting a photon, there is a line width resulting from the collisions What is this width in terms of the macroscopic Γ? In the theory of natural width, one takes the *sum* of the widths of

the initial and final states. In the present situation, it is shown that one must take the mean *difference*, *viz.*, $\langle \Gamma n_{k+1}; \alpha \rangle_a - \langle \Gamma n_k; \alpha \rangle_a$, where α describes the condition of the rest of the system. An interesting application is in single phonon hyperelastic scattering of neutrons from crystals, as suggested by Van Hove.

Invited Paper

EA11. Band-to-Band Transitions in Alkali Halides. L. APKER, *General Electric Company.* (20 min.)

WEDNESDAY AFTERNOON AT 2:00

Terrace Room

(B. ROSSI presiding)

"Strange Particles"

F1. Associated Production of Strange Particles by 1.1-Bev π^- Mesons in Propane Bubble Chamber.* J. L. BROWN, D. A. GLASER, AND M. L. PERL, *University of Michigan.*—A momentum-analyzed beam of 1.1-Bev π^- mesons from the Brookhaven Cosmotron was used for a study of the associated production of strange particles. Approximately 30 000 pictures were taken with a 12-in. propane bubble chamber. Conclusions concerning angular correlations of decay, angular distribution of production, and lifetimes will be presented on the basis of approximately 120 events with free proton targets involving the associated production of strange particles. Of these hydrogen events identified by means of kinematics, about two-thirds are of the type $\pi^- + p \rightarrow \Sigma^- + k^+$, and about one-third are of the type $\pi^- + p \rightarrow \Lambda^0 + \theta^0$ or $\pi^- + p \rightarrow \Sigma^0 + \theta^0$, where the decays of both neutral V's are observed.

* Work supported by the U. S. Atomic Energy Commission.

F2. Λ^0 and θ^0 Production by 1.9 Bev π^- Mesons in Carbon, Iron, and Lead.* T. BOWEN, F. COOKSON, G. TAGLIAFERRI, AND A. WERBROUCK, *Princeton University*, AND W. H. MOORE, JR., *Brookhaven National Laboratory.*—The production of Λ^0 and θ^0 particles is being studied by means of a large multiplate cloud chamber placed in the 1.9-Bev π^- beam of the Cosmotron. By substituting various plate assemblies containing one-half-inch thick carbon, iron, and lead plates, the dependence of the production cross sections on atomic number can be examined. Preliminary results based upon the scanning of $\sim 20\%$ of the photographs indicate that the probability of V^0 production per nuclear interaction remains approximately constant from carbon ($A = 12$) to lead ($A = 207$) at ~ 0.006 V^0 per interaction. The numbers of events leading to production of a single V^0 and of associated V^0's are: (a) carbon, 9 single, 3 associated; (b) iron, 17 single, 1 associated; (c) lead, 62 single, 5 associated. Further results of the scanning and analysis will be presented.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.

F3. Λ^0 and θ^0 Production by 2.8-Bev Protons in Carbon, Iron, and Lead.* F. COOKSON, T. BOWEN, G. TAGLIAFERRI, AND A. WERBROUCK, *Princeton University*, AND W. H. MOORE, JR., *Brookhaven National Laboratory.*—As a further extension of the production of Λ^0 and θ^0 particles in various nuclei, the same multiplate cloud chamber operated in the 1.9-Bev π^- beam[1] has been also placed in the 2.8-Bev "blown-up" proton beam of the Cosmotron. It is expected that the dependence of the production cross section upon atomic number will indicate whether V^0's mainly originate in the initial interaction of the proton or in the collisions of pion secondaries. Preliminary results of the production in iron indicate that the probability of V^0 production per nuclear interaction is ~ 0.001 V^0 per interaction, or of the order of 20% of the corresponding figure for 1.9 Bev π^- mesons. The implications of the results with regard to direct *vs* indirect production will be discussed.

* Supported by the Joint Program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Bowen, Cookson, Tagliaferri, and Werbrouck (preceding abstract).

F4. Relative Production of Unstable Particles in Iron by Proton and π^- Mesons.* H. BLUMENFELD, E. BOLDT, H. S. BRIDGE, D. O. CALDWELL, AND Y. PAL, *M.I.T.*, AND C. P. LEAVITT, *Brookhaven National Laboratory.*—We have measured the relative production of neutral V particles in iron using protons of mean kinetic energy 2.5 Bev and π^- mesons of 1.8 Bev. The experimental arrangement was a multiplate cloud chamber operated in conjunction with the cosmotron. *Preliminary* results are as follows. The V^0 production cross section for pions is $\sigma > 0.3 \pm 0.1$ millibarns per nucleon, and the ratio of the pion to proton production cross section is 3 ± 1 where the errors are only statistical. Note that no correction has been made for unobserved decay events in the plates and that the absolute cross sections are therefore lower limits; also, in evaluating the cross section ratio, it was assumed that the detection probability for V^0 particles produced by pions was identical to that for V^0 particles produced by protons.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

F5. Charged Σ Hyperons from 1001 K^- Meson Stars.* G. A. SNOW,† W. F. FRY, J. SCHNEPS,‡ M. S. SWAMI, AND D. C. WOLD, *University of Wisconsin.*—Stacks of pellicles exposed in negative channels at the Bevatron were area scanned for stars produced by stopped K^- mesons. 1001 such stars were found. From these stars there emerged 319 charged π mesons, 46 hyperfragments, and 158 charged hyperons as follows: 27 $\Sigma^+ \rightarrow p$ decays from rest; 20 $\Sigma^+ \rightarrow \pi^+$ decays from rest; 14 $\Sigma^+ \rightarrow p$ decays in flight; 26 $\Sigma^\pm \rightarrow \pi^\pm$ decays in flight; 49 Σ^- stars from rest; and 22 Σ^- zero prong stars with Auger electrons. The best single value for the Σ^+ lifetime, as determined from all $\Sigma^+ \rightarrow p$ decays, is $0.98(+0.37, -0.21) \times 10^{-10}$ sec. For the Σ^-, a lifetime of about 2.3×10^{-10} sec is found, with a lower limit of 1.3×10^{-10} sec. However, the lifetime obtained from the $\Sigma^\pm \rightarrow \pi^\pm$ decays in flight, is only $0.32(+0.11, -0.07) \times 10^{-10}$ sec. For 86 $\Sigma^\pm$ decays, the angular distribution of $\theta_{\Sigma\pi}$ was measured, where $\theta_{\Sigma\pi}$ is the angle between the decay π meson, in the Σ cm system, and the initial direction of motion of the Σ. The probability that the observed angular distribution, after being

folded about 90°, comes from an isotropic distribution is about 10%.

* Supported in part by the U. S. Atomic Energy Commission and by the Wisconsin Alumni Research Foundation.
† Permanent address: Naval Research Laboratory.
‡ Now at Tufts University.

F6. K^- Particle Captures on Protons in Nuclei.* R. S. WHITE, F. C. GILBERT, AND C. E. VIOLET, *University of California, Livermore.*—From 330 K^- particle captures at rest in nuclear emulsion, events have been selected for analysis in which the capture star consists of only two prongs, one of which is a π meson. A model for K^- capture on protons in nuclei will be presented to explain the observed angle and energy correlations. An analysis of the heavy prongs gives 13.5 Σ^+ and 10.5 or 7.5 Σ^- hyperons depending upon the interpretation of the data. Including the 4 measured two-prong events of the Chicago group[1] the Σ^+/Σ^- ratio is 15.5/12.5 or 15.5/9.5. Σ-hyperon energy distributions will be shown as evidence that Coulomb forces shift the Σ^--hyperon energy spectrum down and the Σ^+ spectrum up and that this shift suppresses the Σ^--hyperon yield and accounts for the high Σ^+/Σ^- ratio. In Σ^--hyperon captures the ratio of the number of events with zero or one prong to those with two or more prongs is 6/4 or 3/4. The nuclear proton momentum distribution, the angular distribution of emission of the Σ hyperons in the center-of-mass system, and the meson energy distribution as determined from these events will be presented.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Haskin, Bowen, Schein, Phys. Rev. **103**, 1512 (1956).

F7. Energy Dependence of the K^+-Meson Interaction Cross Section.* D. M. RITSON, D. FOURNET DAVIS,† AND R. SCHLUTER, *Massachusetts Institute of Technology*, A. PEVSNER, *Johns Hopkins University*, M. WIDGOFF, *Harvard University*, AND V. HENRI, *Northeastern University.*—Observations have been made on three emulsion stacks: one exposed to a 250-Mev/c K^+-meson beam at the Cosmotron, one to a 400-Mev/c K^+ beam at the Bevatron, and the third to a 600-Mev/c K^+ beam at the Bevatron. Interactions with emulsion nuclei have been observed by following tracks showing the appropriate grain density for K^+ mesons of the beam momentum. About 75 meters of K^+-meson track have been followed, and the observed interactions are now being analyzed. The nature of the interactions and the energy dependence of the interaction cross section will be discussed.

* Assisted by the joint program of the Office of Naval Research and U. S. Atomic Energy Commission.
† Now an American Association of University Women Fellow at the University of Rochester, Rochester, New York.

F8. Nuclear Interaction of High Energy K^+ Mesons.* B. SECHI ZORN AND G. T. ZORN, *Brookhaven National Laboratory.*—In a magnetically separated beam, realized at the Cosmotron, nuclear emulsions have been exposed to K^+ mesons at an incident energy of 213 Mev, and the nuclear interaction in photographic emulsions of K^+ particles in the energy interval between 210 and 130 Mev is now being studied. Thus far 32.4 meters of K track in this energy interval has been followed, and 49 interactions resulting in a noticeable loss in K-particle energy or a presumed charge exchange have been observed. This corresponds to a mean free path of 66 ± 9 cm which is significantly smaller than the value for inelastic scattering of $\sim$100 cm obtained in an energy interval of 40 to 160 Mev.[1] The decrease in mean free path with increasing K-particle energy is further confirmed through a division of our data in two energy intervals. The mean free path for the interval between 210 and 180 Mev is 57 ± 11 cm compared with a value of 77 ± 16 cm for the interval 180−130 Mev. More accurate values of the mean free path and details on the nuclear interaction at these energies will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Lannuti, Chupp, Goldhaber, Goldhaber, Helmy, Iloff, Pevsner, and Ritson, Phys. Rev. **101**, 1617 (1956); N. Dallaporta, Sixth Annual Rochester Conference on High Energy Nuclear Physics (April, 1956).

F9. Scattering of K_L and τ Mesons.* T. F. HOANG,† M. F. KAPLON, AND R. CESTER,‡ *University of Rochester.*—A systematic study of the scattering of 1175 K_L mesons and 242 τ and τ' mesons[1] has been made in the energy region of 20 to 80 Mev using Bevatron K^+ mesons recorded in Ilford *G5* emulsions. All scatters of K meson having a projected angle greater than 2° in the emulsion plane were analyzed. A scattering is accepted as elastic if no energy loss can be detected on the basis of ionization and range. The same differential cross section of elastic scattering was observed for K_L and τ mesons. An attempt was made to separate nuclear scattering from coulomb scattering by means of an energy-dependent cutoff. The elastic nuclear scatterings thus found gave a mean free path of $44(+6, -4)$ cm for the K_L meson and $43(+12, -8)$ cm for the τ meson; their angular distribution shows the characteristic features of a diffraction scattering. The ratio of inelastic to elastic ($\Delta E/E<10\%$) scatterings of K_L and τ mesons was found to be $\sim$1/11.

* Supported in part by U. S. Atomic Energy Commission and the Office of Scientific Research of the U. S. Air Force.
† On leave from Laboratoire Leprince-Ringuet, Ecole Polytechnique, Paris.
‡ Now at Istituto di Fisica, Turin, Italy.
[1] Most of the scattering data for the τ mesons were obtained from events found in connection with the systematic study of abundances done by the Richman group at Berkeley. The authors are most grateful to Dr. R. W. Birge and Dr. M. Whitehead for the loan of their plates and scanning data.

F10. Mean Free Path and Mean Life of K^- Mesons.* J. HORNBOSTEL, E. O. SALANT, AND G. T. ZORN, *Brookhaven National Laboratory.*—In the experimental arrangement previously described,[1] stripped emulsions were exposed to a beam of magnetically analyzed negative particles produced by Cosmotron protons. By track scanning, a total of 219 K^- mesons were found in 11 stacks. Except for K^- mesons at rest making a star, the masses of all interacting particles were determined by grain count and multiple scattering. 44 interactions caused by K^- mesons in flight, in the energy interval 15−110 Mev, were identified. A mean free path of 20 ± 3 cm is derived,[2] in agreement with our earlier value.[1] The interactions include 2 $K^- - p$ scatterings, which give the K^- mass close to the τ mass, and 3 inelastic K^--nucleus scatterings. Charge exchange scatterings are $\lesssim$0.1 of all interactions in flight. Out of 276 K^- mesons, observed in 17 stacks, 7 decays in flight gave a K^- mean life of $(1.1\pm0.4)\times10^{-8}$ sec.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] J. Hornbostel and E. O. Salant, Phys. Rev. **102**, 502 (1956).
[2] D. M. Fournet and M. Widgoff, Phys. Rev. **102**, 929 (1956), give $\lambda=36.2$ cm.

F11. Heavy Meson Lifetimes.* S. TAYLOR, G. HARRIS, AND J. OREAR, *Columbia University.*—Previous K-meson lifetime measurements at this laboratory[1] have been extended by the exposure of 2 additional nuclear emulsion stacks in the Bevatron focused K^+ beam. The two exposure positions were separated by a distance corresponding to a proper time of flight for K mesons of 0.7×10^{-8} sec. Along-the-track scanning is employed to locate K endings, and all single secondaries with dip angle $<46°$ and grain density >1.25 times minimum are followed. The number of K mesons found to date in the near stack and the far stack, and the ratios of these numbers, are as follows: K_L: $1557/656=2.37\pm0.11$; τ: $93/38=2.4\pm0.5$; τ': $29/15=1.9\pm0.6$; $K_{\mu3}$: $31/9=3.4\pm1.3$. The errors are the statistical standard deviations. The ratios are the same within

statistics, and hence the data is consistent with a hypothesis of a single lifetime for all K mesons.

* Work supported by the Office of Naval Research, the U. S. Atomic Energy Commission, and the National Science Foundation.
[1] Orear, Harris, and Taylor, Phys. Rev. **104**, 1463 (1956).

F12. Angular Distribution of Prongs of Stars Produced by 3.0-Bev Protons.* GABRIEL KANE, *Manhattan College.*—Stars produced by 3.0-Bev protons from the Brookhaven Cosmotron have been located by area scanning of a stack of Ilford G-5 emulsions. Measurements on the projected angles of about five hundred stars will be reported. All types of tracks show a marked asymmetry in the forward direction. This asymmetry is most pronounced for minimum and grey tracks. However, it is noteworthy even for black tracks. These results will be compared with those of other observers at 2.2 Bev,[1] 5.7 Bev,[2] and 6.0 Bev.[3] In addition, the theoretical basis for this distribution will be discussed. We wish to acknowledge the assistance of Dr. Edward O. Salant of Brookhaven in exposing this stack to the Cosmotron.

* Assisted in part by Research Corporation.
[1] Smith, Leavitt, Shapiro, Swartz, and Widgoff, Phys. Rev. **92**, 851 (1953).
[2] Cavanaugh, Haskin, and Schein, Phys. Rev. **100**, 1263(A)(1955).
[3] U. Haber-Schaim, Phys. Rev. **100**, 1263(A) (1955).

WEDNESDAY AFTERNOON AT 1:45

Panel Room

(J. H. VAN VLECK presiding)

Magnetism II: Ferroelectricity

FA1. Magnetic Susceptibility of a Sintered Rod of MnS.* ROBERT LINDSAY† AND J. J. BANEWICZ, *Southern Methodist University.*—The magnetic susceptibility of a sintered rod of the antiferromagnetic compound MnS has been measured at field strengths of 1075, 1530, and 1980 oersteds by a method elsewhere described.[1] The purity of the sample was determined to be better than 99% with respect to MnS. Irregularities were noted in the susceptibility in the Néel region between 180°K and 140°K which were considered to be outside the limit of experimental uncertainty. These irregularities are characterized by a series of multiple peaks of small amplitude which appear at the same temperatures for all three field strengths. The sharpest change in over-all susceptibility still seems to occur in the vicinity of 154°K in agreement with the previous results on MnS.[1] It is suggested that these fine structure-like peaks represent a transition between short-range and long-range magnetic ordering and might be related to the growth of antiferromagnetic domains. Specific heat data on MnS have previously indicated the existence of a split peak at 139°K and 147°K.[2]

* Assisted by a grant from the Research Corporation.
† Now at Trinity College.
[1] J. J. Banewicz and R. Lindsay, Phys. Rev. **104**, 318 (1956).
[2] C. T. Anderson, J. Am. Chem. Soc. **53**, 476 (1931).

FA2. On the Magnetic Annealing Effect in Cobalt-Substituted Magnetite Single Crystals. R. F. PENOYER AND L. R. BICKFORD, JR., *IBM Research Laboratory.*—Two conclusions drawn[1] from previous work on magnetic annealing in iron-cobalt and zinc-iron-cobalt ferrites containing a large concentration of cobalt are: the magnitude of the field-induced uniaxial anisotropy is independent of annealing field orientation, and the uniaxial preferred direction coincides with the direction of the annealing field. We have studied the effects of magnetic annealing on the anisotropy of single crystals in the composition series $Co_xFe_{3-x}O_4$, with $x=0.01$ and 0.04. The magnitude of induced uniaxial anisotropy in these crystals with low cobalt concentration is strongly dependent on the annealing field direction, and the uniaxial preferred direction does not usually coincide with this direction. The results obtained from (100), (110), and (111) plane torque curves are consistent with the relative magnitude and phase of the uniaxial anisotropy predicted by applying Néel's[2] atomic ordering model to a body-centered cubic lattice. Evidently, whatever is responsible for the field-induced anisotropy, whether it be precipitate or atomic interaction, has axes of uniqueness along body diagonals. Various hypothetical models will be discussed, together with observed time, temperature, and concentration effects.

[1] Bozorth, Tilden, and Williams, Phys. Rev. **99**, 1788 (1955).
[2] L. Néel, J. phys. radium **15**, 225 (1954).

FA3. Polarized Beam Neutron Diffraction Spectrometer.* C. G. SHULL,† R. NATHANS,‡ AND A. W. MCREYNOLDS, *Brookhaven National Laboratory.*—A description will be given of one of the BNL neutron diffraction spectrometers which has been modified for use as a polarized beam spectrometer. By using a magnetized, ferromagnetic crystal of suitable scattering properties as a monochromator, a beam of high polarization value is available for further study. Crystals of Fe_3O_4 have been used as polarizing monochromators and, when due allowance is made for internal depolarization (arising from incomplete magnetic saturation), the theoretical polarization of 100% is accounted for within experimental error of 1%. The magnetic scattering by crystals of iron and nickel has been studied and the magnetic scattering effects are found to be much enhanced over that found with unpolarized radiation. Other advantages of the polarized beam technique will be outlined.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† At Massachusetts Institute of Technology.
‡ At Pennsylvania State University.

FA4. Polarization Neutron Studies on Antiferromagnetic Single Crystals.*—R. NATHANS, T. RISTE,† G. SHIRANE, AND C. G. SHULL,‡ *Brookhaven National Laboratory.*—The theory of neutron scattering by magnetic crystals as given by Halpern and Johnson predicts changes in the polarization state of the neutron beam upon scattering which depend upon the relative orientation of the neutron polarization vector and the crystal magnetic axis. This has been investigated experimentally using the polarized beam spectrometer described above with single crystals of Cr_2O_3 and α-Fe_2O_3 in which reside unique antiferromagnetic axes. To establish the polarization of the scattered neutrons, the single transmission effect in a magnetized block of iron was utilized. Studies were made on several different reflections in both crystals for a number of different temperatures both below and above the Néel point. Our results support the theoretical predictions and indicate directions for the moments in these crystals consistent with previous work. In addition to the above, a more detailed study of the intensity and polarization changes in the (100) and (111)

reflections in α-Fe_2O_3 at room temperature on application of a magnetic field have also been carried out.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† On leave from JENER, Kjeller, Norway.
‡ At Massachusetts Institute of Technology.

FA5. Magnetization of Nickel Ferrite-Chromite. T. R. McGUIRE AND S. W. GREENWALD, *U. S. Naval Ordnance Laboratory.*—Thermal magnetization curves (77°K to T_c) of $NiOCr_tFe_{2-t}O_3$ yield Bohr magneton values per molecule estimated for 0°K which decrease linearly from 2.3 to $0.4\mu_B$ as t increases from 0 to 1. For $t=1.5$, the value is $0.63\mu_B$. The curves are generally the flat Néel type R except for $t=1$ which is type N with a compensation point. The compensation temperature varies with the heat treatment; it decreases from 450°K to 310°K for specimens quenched in water from 1700°K and 900°K, respectively. In both cases the Curie temperature remained at 690°K but the moment (0°K) changed from 0.9 to $0.4\mu_B$. Assuming that Ni remains on the B sites, one can describe the behavior in terms of antiparallel saturated lattices up to $t=1$. Deviations occurring at $t=1.5$ and 2 can be explained by either an unsaturated lattice or by some angular spin arrangement. Substitution in $t=1$ of a small amount (0.25) of zinc for nickel yields the increase in the magnetization expected if the B lattice is dominant at low temperatures. It is not yet clear whether the A or B lattice has the greater moment for greater chromium content, nor has microwave resonance absorption been detected for these cases so far.

FA6. Magnetization Processes in Single-Crystal Cobalt Ferrite with "Sticky" Walls. J. O. ARTMAN,* *Harvard University,* AND S. FONER,† *Lincoln Laboratory.*—Magnetization measurements have been made on a single crystal cobalt ferrite sphere in uniform magnetizing fields using a vibrating sample magnetometer.[1] M *vs* H was not identical along the easy directions (cube edges). In certain "easy" directions, the initial dM/dH, μ_i was small until a critical field H_c was reached, after which M jumped to saturation. At 293°K H_c was about 3 kilo-oersted; at 77°K H_c was greater than 6 kilo-oersted and large hysteresis effects were observed. In other directions μ_i could be large; however, saturation was not easily achieved because of high crystalline anisotropy. In contrast with the usual assumptions made for single-crystal low-field magnetization processes, many features observed here can be explained if we assume that certain domain walls are "sticky." These walls may be pinned by precipitates such as those observed in similar crystals.[2] The magnetization mechanism presented here does not require shape anisotropy as suggested previously.[2] These results have direct bearing on cobalt ferrite heat treatment in magnetic fields, torque reversal curves, magnetostriction,[3] multiple ferromagnetic resonances, and permanent magnets.

* This work was supported by the U. S. Air Force under contract.
† This work was supported jointly by the Army, Navy, and Air Force under contract with M.I.T.
[1] S. Foner, Rev. Sci. Instr. **27**, 548 (1956).
[2] Williams, Heidenreich, and Nesbitt, J. Appl. Phys. **27**, 85 (1956); Bozorth, Tilden, and Williams, Phys. Rev. **99**, 1788 (1955).

FA7. Anomalous Behavior of the Uniform Precessional Ferrimagnetic Resonance Mode. I. H. SOLT, JR., AND R. L. WHITE, *Hughes Research Laboratories.*—It has been shown[1] that in a ferrimagnetic resonance experiment in which the sample has been placed in a nonuniform rf magnetic field, one can excite numerous precessional modes which correspond to different spatial distributions of the rf magnetization. The uniform mode is the one usually considered in the literature. It can be distinguished experimentally from the more complicated modes because (a) the intensity of its absorption decreases much less rapidly with diminishing sphere size than for the higher modes and (b) it is maximally excited at a position of uniform rf magnetic field. We have observed, however, that as sample size is decreased not one but several lines possessing the characteristics of the uniform mode remain. The relative intensities of these lines are strong functions of both temperature and frequency. They have different anisotropy constants and their separation decreases with sphere radius. Data will be presented for experiments on spherical single crystals of Mn-Zn ferrites performed in the microwave frequency range of 8000 to 12 000 Mcps.

[1] R. L. White and I. H. Solt, Jr., Phys. Rev. **104**, 56 (1956). J. E. Mercereau and R. P. Feynman, Phys. Rev. **104**, 63 (1956). L. R. Walker, Phys. Rev. (to be published).

FA8. Effective Cubic Magnetic Anisotropy in Ferromagnetic Resonance. R. L. WHITE AND I. H. SOLT, JR., *Hughes Research Laboratories.*—The existence of magnetic anisotropy causes the magnetic field required for ferromagnetic resonance at fixed frequency to be a function of crystal orientation, for single crystal samples. The precise form and amplitude of the excursion of resonant field can be interpreted to yield the magnetic anisotropy constants of the material. For the uniform precessional mode these constants are the same as the static anisotropy constants. For the higher modes of resonance, the zonal distribution of precessional phase yields, through simple dipole-dipole coupling, an additional magnetic anisotropy of first order magnitude. The calculation of this energy will be described and data on the experimentally determined anisotropies presented.

FA9. Ferrimagnetic Resonance in Yttrium Iron Garnet at Liquid Helium Temperatures. J. F. DILLON, JR., *Bell Telephone Laboratories.*—Ferrimagnetic resonance experiments have been performed on single-crystal spheres of yttrium iron garnet[1] ($Y_3Fe_2(FeO_4)_3$) at 24 000 mc. Preliminary results in the temperature range up to the Curie point have been reported briefly.[2] Further and more complete results at temperatures below 5°K will be given in this paper. There is a peak in the line width *vs* temperature curve between 20° and 65°K. At 4.2° the line width measured with the steady field along [100] is 15 oe, as compared with 30 oe at 295°, 400 oe at 65°K. At liquid helium temperatures the crystal is apparently cubic. There is a strong anisotropy in line width. Except for the case of the field along [100], the line width varies strongly with temperature in this temperature region. A large magnetocrystalline anisotropy is indicated by the variation in field for resonance with direction. This ranges over 3000 oe. The maxima and minima in this field indicate that terms of higher order than the K_1 and K_2 terms used hitherto will be necessary for the description of the anisotropy energy surface. Thus, at 4.2°K [100], [110], and [111] are all hard directions, and the easy directions are exactly or close to [112], [221], and [123].

[1] Grown by J. W. Nielsen at the Bell Telephone Laboratories.
[2] J. F. Dillon, Jr. (to be published).

FA10. Ferromagnetic Resonance on Truncated Spheres of Single Crystals of Manganese Ferrite. S. GESCHWIND AND A. M. CLOGSTON, *Bell Telephone Laboratories, Incorporated.*—Ferromagnetic resonance at 24 000 Mc has been done on truncated spheres of single-crystal manganese ferrite. Flats parallel to the 110 plane were ground on the sphere and resonance line widths observed with the dc field parallel to the three principal crystalline directions. The purpose of these flats was to introduce large dc field inhomogeneities in the sample (of the order of the saturation magnetization) to see what effect this would have upon the line width. The flats ranged from a slight perturbation to where nothing but a polar cap was left. The results are that the different line width in the three principal crystalline directions remained unchanged. Thus, although different parts of the sample see different dc fields, they do not oscillate at different frequencies, but are instead coupled by *long-range dipole forces* and oscillate in some ferromagnetic resonance eigenmode of the truncated sphere. The further the flat was ground the lower was the

field required for resonance, as expected. In addition, higher eigenmodes of ferromagnetic resonance of the sample, analogous to those of ellipsoids,[1-3] were excited. This suggests an increased density of the long wavelength modes as well as increased coupling of the rf magnetic field to these modes.

[1] R. L. White and I. H. Solt, Jr., Phys. Rev. **104**, 56 (1956).
[2] J. F. Dillon, Jr., Bull. Am. Phys. Soc. Ser. II, **1**, 125 (1956).
[3] L. R. Walker, Bull. Am. Phys. Soc. Ser. II, **1**, 125 (1956).

FA11. Langevin Equation and the *H* Theorem. ARMAND SIEGEL, *Boston University.*—The Langevin equation, $\dot{\alpha}+\gamma\alpha=a(t)$, where γ is a constant and $a(t)$ is the derivative of the Wiener random function, gives probability distributions for $\alpha(t)$ that are symmetrical in time.[1] Nonetheless, the sample functions show an exponential decay if the initial value of α is fixed. The set of curves $\alpha(t)$ is ergodic; this follows from the ergodicity of the Wiener function.[2] Physically this means that its probability distributions could be duplicated by a set consisting only of a single suitably constructed infinite curve and all those curves obtainable from it by time displacement (all values of time displacement being equally weighted). From the time symmetry of the distributions one can infer that there is no difference between the essential structure of this curve and that obtained from it by reversing the time. Almost all of the curves of the set are *H* curves,[3] reconciling time reversibility with the overwhelming tendency of systems to approach equilibrium. These remarks lend themselves readily to graphical demonstration.

[1] Wang and Uhlenbeck, Revs. Modern Phys. **17**, 323 (1945).
[2] Paley and Wiener, *Fourier Transforms in the Complex Domain* (New York, 1934).
[3] P. and T. Ehrenfest, Enzykl. d. Math. Wiss. Leipzig Vol. IV(2).

FA12. Single-Crystal Neutron Diffraction Refinement of the Tetragonal $BaTiO_3$ Structure.* H. R. DANNER, B. C. FRAZER,† AND R. PEPINSKY,‡ *Brookhaven National Laboratory.*—The previously reported values[1] for the parameters of tetragonal $BaTiO_3$ were deduced from single-crystal neutron data in which a monochromatic neutron beam of 1.063 A limited the observations to Bragg peaks with a maximum index of 6. Subsequent measurements utilizing neutron wavelengths of 0.91 A and 0.73 A have extended the $(h0l)$ observations to an index of 10. In addition, partial (hhl) data has been collected from a second rectangular sample in which the cubic [110] axis was the rotation axis. Here again, unidirectional domain allignment was maintained by the application of an external electric field. A least-squares analysis of the extended $(h0l)$ data has shown that, although the positional parameters were nearly correct, the temperature factors were too small. The results of this analysis give the coordinate parameters as $\delta z_{Ti}=0.013$, $\delta z_{OI}=-0.023$, $\delta z_{II}=-0.014$, and the crystal temperature factor as $B=0.44$.

* Under the auspices of the U. S. Atomic Energy Commission.
† Now a guest at Brookhaven from the Westinghouse Research Laboratories.
‡ Permanently at the Pennsylvania State University.
[1] Frazer, Danner, and Pepinsky, Phys. Rev. **100**, 745 (1955).

FA13. Neutron Diffraction Study of $BaTiO_3$ near the Curie Temperature.* G. SHIRANE, H. DANNER, AND R. PEPINSKY,† *Brookhaven National Laboratory.*—A structural study of ferroelectric $BaTiO_3$ through its Curie point at 120°C was carried out by neutron diffraction technique. The $(h0l)$ reflections were obtained from pillar shaped crystals which were maintained as single domains by the application of a strong dc field. The atomic shifts along the polar axis in the tetragonal phase were studied as a function of temperature and they were found to be linearly proportional to the spontaneous polarization. The behavior of the crystal through the Curie temperature will be discussed.

* Under the auspices of the U. S. Atomic Energy Commission.
† Permanently at the Pennsylvania State University.

FA14. Electrical Conductivity of $BaTiO_3$ Single Crystals.* P. H. FANG, *National Bureau of Standards.*—The determination of the electrical dc conductivity of $BaTiO_3$ is affected by two parameters: (1) the nonuniformity of the field distribution in the crystal, especially near the surface, and (2) the very large time of relaxation for reaching the equilibrium state after the application of a dc field. The measured current shows initially a steady value, decreases to a minimum value, then increases and reaches an equilibrium state with a time of order 10^3 to 10^5 sec. The final current is several orders of magnitudes higher than the value at the minimum. The initial steady state is due to the dielectric absorption from the nonuniform field distribution in the crystal. This phenomenon can be augmented by using a nonsymmetrical electrode arrangement and creating a stronger field on one side of the surface, which influences the formation of electrode layers by the dielectric medium. The change of the conduction current can be caused either by the diffusion of foreign ions from the electrode materials or the self-diffusion through the electrolytic effect of the medium. The repeatability of the experiment over a long period of time indicates that the migration of the foreign ion is negligible. The self-diffusion of Ba in $BaTiO_3$ provides a relaxation time of right order of magnitudes.

* Research supported by the U. S. Atomic Energy Commission.

WEDNESDAY AFTERNOON AT 2:00

Empire Suite

(C. S. WU presiding)

Radioactive Nuclei

G1. Radioactive Breakup of the HT Molecule. ARTHUR H. SNELL, FRANCES PLEASONTON, AND HOWELL E. LEMING,* *Oak Ridge National Laboratory.*—The molecular fragments produced by the beta decay of HT have been subjected to magnetic analysis, and the following ions have been observed with the intensities indicated:

$(He^3H)^+$	93.3%
$(He^3)^+$	5.1
H^+	1.5
$(He^3)^{++}$	0.14

Dissociation with electron shake-off occurs in fewer than 1.6% of the decays. The relative intensities of $(He^3)^+$ and H^+ are reversed from what one would expect on the basis of their ionization potentials.

* Summer collaborator from Chemistry Department, University of Arkansas.

G2. Decay of K^{42}.* N. BENCZER-KOLLER, A. SCHWARZSCHILD, AND C. S. WU, *Columbia University.*—The decay of K^{42} has been reinvestigated in an attempt to clarify the dis-

crepancies existing in the energy levels of Ca^{42}.[1-3] The external conversion spectrum showed lines corresponding to the following γ energies: 0.371 ± 0.002, 0.388 ± 0.002, 0.394 ± 0.002, 0.591 ± 0.003, 0.614 ± 0.004 Mev. The second and third and fourth and fifth lines had not been resolved by Lindquist and Mitchell.[1] This may explain the disagreement between their conclusions and those of Braams *et al.*[3] In the scintillation spectrum the following γ rays were observed: 0.220 ± 0.005, 0.375 ± 0.005, 0.615 ± 0.005, 1.005 ± 0.010 Mev. The relative intensities of all these γ rays are: 0.220 Mev (<5), 0.371(100), 0.388(14), 0.394(16), 0.591(23), 0.614(91), 1.005(3.5). β–γ and γ–β coincidence measurements establish that the gamma transitions to the ground state are the 0.371-Mev and the 0.591-Mev γ rays, and not the 0.614 Mev.[1] These results and the γ–γ coincidence measurements indicate only one possible level scheme in Ca^{42}: 0, 0.371, 0.591, 0.985, 1.373 Mev. These energy levels as well as their possible spin and parity assignments are in very good agreement with the results of Braams *et al.*[3]

* This work was partially supported by the U. S. Atomic Energy Commission.

[1] T. Lindquist and A. C. G. Mitchell, Phys. Rev. **95**, 444 (1954).
[2] T. Lindquist and A. C. G. Mitchell, Phys. Rev. **95**, 1635 (1954).
[3] C. M. Braams, Ph.D. thesis (1956).

G3. Gamma-Radiation from Mn^{56}. C. SHARP COOK AND F. M. TOMNOVEC, *U. S. Naval Radiological Defense Laboratory.*—The gamma-radiation from Mn^{56} has been measured using a 4-in. diam, 4-in. high cylindrical NaI(Tl) crystal and a 20-channel pulse-height analyzer operated to record information over 100 channels. Based on an intensity of 1.00 for the 0.845-Mev gamma ray, the following intensities are observed: 1.81 Mev, 0.29; 2.13 Mev, 0.15; 2.65 Mev, 0.018; and 2.98 Mev, 0.004.

G4. Decay of Br^{84}. NOAH R. JOHNSON AND G. D. O'KELLEY, *Oak Ridge National Laboratory.*—The radiations from the decay of 31.8-min Br^{84} have been examined with single crystal and coincidence scintillation spectrometers. Using a 3-in.×3-in. NaI crystal spectrometer the decay showed gamma-rays of 0.879 ± 0.007, 1.02, 1.23, 1.51, 1.71, 1.92, 2.22, 2.50, 3.03, 3.29, and 3.93 ± 0.04 Mev, together with as yet unresolved low-energy gamma-ray components. The maximum beta-ray end-point energy measured with an anthracene crystal spectrometer was 4.76 Mev. This group is not in prompt coincidence with any of the gamma rays and is therefore believed to be the transition to the ground state of Kr^{84}. Beta-gamma coincidence measurements indicated other beta-ray components of 0.83, 1.39, 1.81, 2.84, and 3.83 Mev. The gamma-ray spectra in coincidence with the 0.879-, 1.92-, 2.50-, and 3.93-Mev gamma rays were also measured. Twenty-five percent of the Br^{84} beta decays go to the ground state of Kr^{84}. A decay scheme compatible with these data will be discussed.

G5. Decay Chain Mo^{101}-Tc^{101}. G. D. O'KELLEY, Q. V. LARSON, AND G. E. BOYD, *Oak Ridge National Laboratory.*—The decays of 14.0 ± 0.1-minute Tc^{101} and its parent, 14.61 ± 0.07-minute Mo^{101}, have been studied by scintillation methods. Sources of Mo^{101} were measured shortly after chemical purification from the Tc^{101} daughter. Gamma rays having energies of 0.0833, 0.193, 0.403, 0.515, 0.585, 0.707, 0.896, 1.02, 1.19, 1.54, 1.68, and 2.08 Mev were determined. The maximum energy beta-ray group was 2.23 ± 0.04 Mev. Sources of the Tc^{101} daughter were chemically isolated from the Mo^{101} parent and rapidly examined. In the single crystal experiments, gamma-rays of 0.130, 0.186, 0.235, 0.307, 0.410, 0.545, 0.635, 0.720, 0.846, and 0.939 Mev were detected, and their relative intensities measured. Gamma-gamma coincidence spectrometry was employed to formulate a decay scheme with levels in Ru^{101} at 0.130, 0.307, 0.316, 0.410, 0.545, 0.635, 0.720, 0.846, and 0.939 Mev. The most energetic and intense beta-ray group was determined as 1.32 ± 0.03 Mev and was in coincidence with the 307-kev gamma ray; a second 1.07 ± 0.05-Mev group was coincident with the 545-kev gamma ray. Rapid chemistry showed no isomeric Tc^{101} with a half-life exceeding 5 seconds.

G6. *K*-Capture-Positron Ratios for First-Forbidden Transitions: Sb^{122}, Rb^{84}, I^{126}, As^{74}.* M. WOLFSBERG, J. WELKER, AND M. L. PERLMAN.—The general theory of branching ratios, *K* capture to positron emission, is discussed. The effects of various corrections, especially screening corrections, are studied. New experimental data for a first-forbidden transition with spin change two in Sb^{122} are presented. Comparison between theory and experiment is made for allowed transitions and for first-forbidden transitions with spin change two and zero. The results are used to make deductions about the beta decay interactions and the relative magnitudes of nuclear matrix elements.

* Research carried out under the auspices of the U. S. Atomic Energy Commission.

G7. Decay of Ce-Pr^{144}.* R. L. HICKOK,† W. A. MCKINLEY, AND S. C. FULTZ,‡ *Rensselaer Polytechnic Institute.*—The beta and gamma spectra from the decay of Ce-Pr^{144} has been investigated by means of a magnetic lens spectrometer and a single-channel scintillation spectrometer. Three partial beta spectra with end-point energies and relative intensities of 184 kev (30%), 245 kev (10%), and 320 kev (60%) were observed for Ce^{144}. Internal conversion lines corresponding to gamma rays having energies of 54, 80, and 134 kev were also detected. Internal conversion coefficients indicate an *M*1 multipolarity for the 80-kev and 134-kev transitions and either an *M*2 or *E*3 for the 54-kev transition. Pr^{144} yields three partial beta spectra with end-point energies and relative intensities of 0.90 Mev (2%), 2.45 Mev (3%), and 3.15 Mev (95%). Corresponding gamma rays were also detected. The proposed decay scheme has been substantiated by beta-gamma and gamma-gamma coincidence measurements. Tentative assignment of spin and parity for the state of Pr^{144} will be presented.

* Supported in part by a grant from the Research Corporation.
† Now at Yale University.
‡ Now at University of California, Livermore.

G8. X-Rays Associated with Samarium-145. G. W. CALLENDINE, JR., W. E. CAREY, AND M. L. POOL, *The Ohio State University.*—Samarium oxide enriched to 85.72% in isotope of mass number 144 was irradiated in the LITR reactor for a period of 63 days. Cauchois spectrographic measurements taken four months after irradiation reveal lines with energies of 38.62 kev, 38.15 kev, 43.60 kev, 45.00 kev, and 61.3 kev. The first four of these lines are attributed to the $K\alpha_1$, $K\alpha_2$, $K\beta_1$, and $K\beta_2$ x-rays associated with promethium. The 61.3-kev line is a gamma ray associated with the decay. Gamma scintillation spectrometer studies show 38 kev and 62-kev photoelectron peaks consistent with the Cauchois studies. These two peaks are in coincidence with each other. No other gamma rays of higher energy can be associated with the samarium-145 isotope. Half-life measurements by gamma spectrometer and Geiger counter show that both the x-rays and the gamma-ray decay at the same rate. No beta particles, positrons, or alpha particles could be detected. A decay scheme for the one year activity of samarium-145 is proposed.

G9. Radiations from W^{185} and W^{187}.* V. S. DUBEY,† C. E. MANDEVILLE, A. MUKERJI,‡ AND V. R. POTNIS,§ *Bartol Research Foundation.*—The radiations of W^{185} and W^{187} have been examined in a thin-lens spectometer and with coincident scintillation spectrometers. W^{185} has been found to emit no gamma rays. Its beta spectrum terminates at 435 ± 5 kev and has an allowed shape. The complex beta spectrum of W^{187} has been resolved into three components of maximum energies

1320±20 kev (log ft=7.9), 620±10 kev (log ft=6.4), and 330±20 kev (log ft=6.5). A Fermi-Kurie plot of the most energetic spectrum showed it to have the unique first forbidden shape ($\Delta I=2$; yes!). Internal conversion lines and photoelectric conversion lines in lead and gold indicated the presence of gamma rays from W^{187} at quantum energies of 73 kev, 108 kev, 136 kev, 208 kev, 224 kev, 243 kev, 485 kev, 512 kev, 621 kev, 627 kev, 688 kev, 777 kev, and 866 kev.

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† On leave of absence from Agra College, Agra, India.
‡ On leave of absence from the Tata Institute of Fundamental Research, Bombay, India.
§ Permanent address, Gwalior (M.B.), India.

G10. Decay Scheme of Os^{190m} (10 min). G. SCHARFF-GOLDHABER, D. E. ALBURGER, G. HARBOTTLE, AND M. MCKEOWN, *Brookhaven National Laboratory.**—Although the decay-scheme of the even-even isomer Os^{190m} has some similarity with that of Hf^{180m}, it differs from the latter in that Os^{190} lies in the transition region between the rotational and the near-harmonic level schemes. Its decay via 4 successive γ rays as established previously[1] was confirmed. Internal conversion electron studies by means of an intermediate image spectrograph yielded γ-ray energies of 187±1 kev, 359±2 kev, 500 ±3 kev, and 614±3 kev. It may be inferred from Coulomb excitation work[2] that the 187-kev transition leads to the ground state, but the sequence of the 3 other gamma rays is not yet known. The K conversion coefficients and K/L ratios measured indicate four successive $E2$ transitions. The lifetime determining isomeric transition has not yet been found.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] Aten, Feyfer, Sterk, and Wapstra, Physica **21**, 740, 990 (1955).
[2] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **93**, 906 (1954).

G11. Gamma-Electron and Electron-Gamma Angular Correlation Measurements in Pt^{196}.* J. V. KANE, *Brookhaven National Laboratory*, AND S. FRANKEL, *University of Pennsylvania.*—Gamma-electron and electron-gamma measurements have been obtained for the 2+, (334.0), 2+, (356.5) 0+ cascade to the ground state in Pt^{196}, using a twin-lens electron spectrometer and an NaI(Tl) scintillation detector. The values of A_2 and A_4 obtained after correction for the solid angles of the counter and spectrometer are $(\gamma-e_K^-)$ $A_2=+0.055\pm0.015$ and $A_4=-0.013\pm0.015$, and $(e_K^--\gamma)$ $A_2=-0.048\pm0.013$ and $A_4=-0.016\pm0.014$. The results obtained for A_2 are consistent with the earlier γ–γ measurements of Steffen[1,2] as regards the $E2/M1$ mixture of the upper transition but are both lower than the expected values by a wipe-out factor $G_2\sim0.4$. The G factor is attributed to electron scattering in the source. No significance is claimed for the A_4 terms. These results do not show evidence for admixture due to electric monopole internal conversion[3] in the upper transition.

* This work was supported in part by the Office of Ordnance Research, U. S. Army.
[1] R. M. Steffen, Phys. Rev. **80**, 665 (1953).
[2] M. T. Thieme and E. Bleuler, Phys. Rev. **101**, 1031 (1956).
[3] E. L. Church and J. Weneser, Phys. Rev. **103**, 1035 (1956).

WEDNESDAY AFTERNOON AT 2:00

North Ballroom

(K. A. BRUECKNER presiding)

Theoretical Physics, II: Nuclear Theory

GA1. Influence of Various Potential Parameters on Nuclear Energy Levels.*† A. E. S. GREEN, *Florida State University.*—A program has been devised for the ORNL Oracle which yields precise neutron and proton eigenvalues for spherical potentials with a range of possible (a) surface shapes, (b) radii, (c) well depths, (d) velocity dependences, (e) spin orbit couplings, (f) proton anomalies, and (g) charge numbers. In the design and application of the program, consideration has been given to previous experience with analytical solutions. This experience indicates, among other things, that self-consistent nuclear potentials are expected to depart significantly from any family of potentials whose parameters depend simply upon the mass number. Accordingly it appears desirable to investigate carefully the influences of variations of the various parameters upon nuclear energy level structures. Analytical convenience and speed of computation have governed the choice of potentials used thus far for general studies of static and velocity-dependent potentials.

* This work was begun at the Oak Ridge National Laboratory during the summer of 1956 with the aid of Dr. H. C. Griffith of the Mathematics Panel and is being continued with the aid of Dr. T. W. Hildebrandt and the ORINS ORACLE Applications Program.
† Supported by grant from the U. S. Atomic Energy Commission.

GA2. Interaction of a Nucleon with the Nucleus. ERICH VOGT AND HUGH MCMANUS, *Atomic Energy of Canada Ltd.*—The physical basis for the use of the shell model in the nucleon-nucleus interaction has been investigated. A state of the whole nucleus is constructed consisting of a product of a target nucleus state and a wave function for the incident nucleon. The wave function of the incident nucleon is the usual type of single particle state. The target state contains correlations in position between the target nucleons and the incident nucleon.[1] The product of these states solves, approximately, the Schrodinger equation for the whole nucleus. The best approximation is obtained by minimizing the second moment, M_2, of the strength function[1] corresponding to the product state. It is shown that a reasonably small M_2 is obtained only when the Pauli Principle is used in antisymmetrizing the target state and when there exist strong correlations (polarization) of the positions of the target nucleons to the incident nucleon. A simple approximate method for calculating M_2 is given. The exact minimum value of M_2 depends on the detailed shape of the two nucleon potential. Even with repulsive cores in the two nucleon potential M_2 is reasonably small. Detailed results for a variety of potentials are obtained.

[1] Erich Vogt, Phys. Rev. **101**, 1792 (1956).

GA3. A Study of the Solutions to the Hartree-Fock Equations for the Nucleus. J. AVILES AND R. JASTROW, *U. S. Naval Research Laboratory.*—The Hartree-Fock equations for the ground state of the He^4 nucleus have been investigated numerically by an iterative (self-consistent) procedure. It is found that the result of the iteration is affected by the choice of starting trial function. Two nodeless solutions are found: (a) a bound state whose radius is slightly larger than the range of the two-body nuclear forces; (b) a state of virtual binding whose radius is substantially greater than the range of forces.

Assuming a Yukawa attraction for the nucleon-nucleon potential, the energy of the bound state is 10 Mev, to be compared with 55 Mev obtained by Irving in a calculation with the same nuclear forces but with correlations included in the trial function.

GA4. Many-Body Problem with Strong Forces. R. J. DRACHMAN, J. B. AVILES, AND R. JASTROW, *U. S. Naval Research Laboratory.*—A trial solution constructed from two-body functions of arbitrary form is applied to a variational treatment of the many-body problem with strong interactions. The two-body function is found to satisfy a simple wave equation, which describes the motion of two particles in a field consisting of the actual two-body potential plus an effective potential resulting from collisions with other particles. The effective potential has a finite range, of the order of the mean particle spacing in the system. The wave equation is a nonlinear integro-differential equation, whose solutions are easily found for the case of the hard sphere Bose gas at low densities. For this gas we find the following expansion of the zero-point energy (T) in terms of particle density (ρ) and hard sphere radius (a):

$$T=\frac{\hbar^2}{2m}4\pi a\rho[1+c_1(\rho a^3)^{\frac{1}{2}}+c_2(\rho a^3)+\cdots],$$

with $c_1\sim 5$, $c_2\sim 9$. Similar calculations are in progress for the gas of hard sphere fermions.

GA5. Hard Core Nucleon-Nucleon Interaction with Morse-type Potential. EUGENE GUTH, *Oak Ridge National Laboratory.*—The proton-neutron interaction in the singlet state has been in the past approximated by a nonanalytic function (e.g., an exponential which was cut off at a certain radius where the potential was assumed to become infinitely steep) (e.g., Jastrow). In the present work analytic functions of the Morse-type are used instead, permitting a solution in terms of known functions for $l=0$. For higher angular momenta, approximations of the type used in the theory of molecular structure might be employed in certain cases. The early (1936–1937) work by Morse, Schiff, and Fisk assumed the whole (central) interaction between proton and neutron to be of the form of a Morse potential which is not the case according to our present knowledge. Various applications and implications of our approximations of a hard core by analytic potentials will be given and discussed in some detail.

GA6. Time-Dependent Hartree-Fock Theory of Nuclear Collective Oscillations. RICHARD A. FERRELL, *University of Maryland.*—A method recently applied to the collective oscillations of an electron plasma[1] can also be successfully employed in giving a description to nuclear collective oscillations which does not involve introducing extra variables and subsidiary conditions. This time-dependent self-consistent field method yields a value for the frequency of the breathing mode of oscillation of O^{16} which is believed to be more accurate than a previous estimate,[2] but which reduces to the latter in certain cases. By neglecting exchange effects it is also possible to show that the new estimate reduces to the frequency derived from the simple classical theory of a compressible fluid. In the actual case of O^{16} exchange effects are important and the quantum frequency is significantly smaller than the classical frequency, according to preliminary numerical estimates. The rate of de-excitation of the breathing mode by pair emission can also be obtained from the time-dependent theory.

[1] P. S. Zyrianov and V. M. Eleonskii, J. Exptl. Theoret. Phys. U.S.S.R. **30**, 592 (1956).
[2] R. A. Ferrell and W. M. Visscher, Phys. Rev. **102**, 450 (1956).

GA7. Theory of O^{17}: First Excited State Lifetime and Ground State Quadrupole Moment.* S. FALLIEROS AND R. A. FERRELL, *University of Maryland.*—The $(2.5\pm1.0)\times10^{-10}$ sec lifetime of the O^{17} first excited state was measured by Thirion and Telegdi[1] and attributed to deformation of the O^{16} core. A calculation[2] using the shell model and two-body forces yields sufficient deformation. A further consequence is that the ground state admixture of deformed core coupled to the neutron $d_{5/2}$ state, a configuration not considered by the previous authors, gives a negative ground state quadrupole moment many times the experimental value[3] of $-(0.5+0.5, -0.2)e(\text{Fermi})^2$. In the course of this work we have found that, contrary to general belief, there is no recoil contribution of the core to either the transition matrix element or the quadrupole moment. The latter has already been noted by Elliott and Skyrme.[4] Attempts to understand the small experimental value are in progress.

* Research supported by the National Science Foundation.
[1] J. Thirion and V. L. Telegdi, Phys. Rev. **92**, 1253 (1953).
[2] With W. M. Visscher (unpublished). For the shell-model description of the core deformation, see R. A. Ferrell and W. M. Visscher, Phys. Rev. **102**, 450 (1956), and Phys. Rev. **104**, 475 (1956).
[3] Geschwind, Gunther-Mohr, and Silvey, Phys. Rev. **85**, 474 (1952). H. Horie and A. Arima, Phys. Rev. **99**, 778 (1955), have made a configuration-interaction calculation of the quadrupole moment and also obtain too large a quadrupole moment. K. W. Ford finds the same result with the weak coupling model (private communication).
[4] Private communication from A. M. Lane. See also J. P. Elliott and T. H. R. Skyrme, Nuovo Cimento **4**, 164 (1956).

GA8. Quasi-α Nuclear Substructure in *j-j* Coupling.* R. W. KING AND D. W. DORN, *Purdue University.*—Empirical evidence on complex nuclei reveals, in addition to large spin-orbit forces, a tendency for two neutrons and two protons to form a particularly stable ("quasi-α") structure. The *j–j* coupling shell model provides a description of strong spin-orbit effects; however, in all but a few simple nuclei, the model does not lead to uniquely determined wave functions. We have chosen to remove the nonuniqueness of *j–j* coupled wave functions by imposing the maximum amount of quasi-α structure permitted by strong spin-orbit coupling. The α-like structure is associated with two neutrons and two protons in an $S=T=0$ substate; the antisymmetry of the total wave function assures that the substate is completely space-symmetric. The procedure of maximizing this "α" structure thus demands that the dominant parts of nuclear wave functions be formed by pairs of nucleons in relative $T=1$, $S=0$, and $T=0$, $S=1$ states with symmetrical space coupling. This type of pairing appears more realistic than that imposed by the "seniority" quantum number.

* Supported in part by the Air Force Office of Scientific Research.

GA9. Beta Decay Matrix Elements from the Quasi-α Model.* D. W. DORN AND R. W. KING, *Purdue University.*—Allowed beta decay transition probabilities provide a rigid test for low-energy nuclear models. The supermultiplet formalism has remained the only means of obtaining qualitative accord with the experimental evidence on beta decay. In general, the predictions of *j–j* coupling models have been considerably worse.[1] Since the quasi-α model in *j–j* coupling[2] does bear some resemblence to the supermultiplet formalism in *L–S* coupling, it is conceivable that a strong spin-orbit coupling description can be maintained with improved beta decay matrix elements. Specific matrix elements in the $d\,5/2$ and $f\,7/2$ shells have been calculated; the improvement obtained suggests that wave functions constructed from the quasi-α model afford a better description of nuclei than those derived from the use of a "seniority" quantum number.

* Supported in part by the Air Force Office of Scientific Research.
[1] I. Talmi, Phys. Rev. **91**, 122 (1953).
[2] R. W. King and D. W. Dorn, Bull. Am. Phys. Soc. Ser. II, **2**, 26 (1957), preceding abstract.

GA10. Relative Sign of G_S and G_T in Beta Interaction. M. MORITA* AND R. SAITO,† *Columbia University.*—It is the general conclusion that the ratio of $|G_S|/|G_T|$ in beta interaction is close to one. However, the sign is still undertermined.

Recently we investigated, theoretically, the angular distribution of β-particles emitted by oriented nuclei. The results lead us to propose a new method to determine the relative sign of G_S and G_T in beta interaction. The relative sign can be determined by measuring both the angular distribution of the emitted β particles and the shape of the β spectrum. The general angular distribution function of β particles emitted by oriented nuclei will be presented. A few special cases of first forbidden transitions with $(\Delta J)=1$ in odd nuclei will be discussed.

* On leave from Kobayasi Institute of Physical Research, Tokyo.
† On leave from University of Tokyo.

GA11. Dependence of the C^{14} Beta Decay on the Tensor Force.* D. T. GOLDMAN AND R. A. FERRELL, *University of Maryland.*—A tensor force is required to explain both the cancellation in the C^{14} beta decay matrix element and the quadrupole moment of the deuteron. Previous efforts[1] to establish compatibility between these two sources of information on the tensor force have been extended to a larger variety of assumed interaction shapes. For a given shape the strengths of the central and tensor force which reproduce the ground state properties of the deuteron are functions of tensor range. These functions have been used to calculate the C^{14} matrix element also as a function of tensor range. The latter is then determined as the root of this function. Both the Gaussian and the Yukawa shapes give roots, but in the Yukawa case the required tensor strength is excessive. Generally a rapid radial fall-off is necessary, and for the exponential shape, with its gradual variation, we find no root. Especially satisfactory is the highly singular one-meson exchange potential,[2] which yields a relatively effective off-diagonal S–D matrix element without contributing too heavily to the diagonal elements.

* Research supported by the National Science Foundation.
[1] Goldman, Visscher, and Ferrell, Bull. Am. Phys. Ser. II, **1**, 17 (1956). The numerical result stated there for the Yukawa shape is incorrect.
[2] Hiida, Iwadare, and Machida, Progr. Theoret. Phys. **15**, 189 (1956).

GA12. Coulomb Corrections to the Nuclear Matrix Element for $0^+\rightarrow 0^+\beta$ Transitions. W. M. MACDONALD, *University of Maryland.*—The assumption of charge independent nuclear forces gives the nuclear matrix element of $0^+\rightarrow 0^+$ β transitions in the nonrelativistic approximation as $M_F=\int 1=(\sqrt{(T\pm T_B)(T\mp T_B+1)})^1$. This result is independent of any specific nuclear model and has been used by Sherr and Gerhart to provide limits on the ratio (g_V/g_S) of the vector coupling constant to the scalar coupling constant for β decay. The Coulomb forces between protons perturb the wave functions obtained on the basis of charge independence, however, and result in a decrease in the Fermi matrix element. This decrease results both from (1) the mixing of states of different isotopic spin T in a given nucleus, and from (2) a difference in the perturbation of the corresponding states of isotopic spin T in two members of an isotopic spin multiplet. These two effects on the Fermi matrix element will be discussed with reference to the limits which can be set on (g_V/g_S) by the analysis of ft values for $0^+\rightarrow 0^+\beta$ transitions given by Sherr and Gerhart.

GA13. Three-Body Nuclear Interaction in K^{40}. S. P. PANDYA AND J. B. FRENCH, *University of Rochester.*—If we assume only two-body interactions and pure jj coupling, there exists a simple theoretical correspondence between the lowest four levels of Cl^{39} and of K^{40}. Using this, the levels of Cl^{39} have been predicted to within 30 kev from the levels of K^{40}.[1,2] We now ascribe the small discrepancies to the effects of other configurations and possibly of a three-body nuclear interaction (the latter would affect only the K^{40} levels). The interconfiguration effects for both nuclei have been estimated by using the information about the nuclear interaction which is available in this region of A; a more direct estimate will be possible when information becomes available about the higher excited states of both nuclei. After the corrections for the interconfiguration effects are made, the residual effects enable us to derive an upper limit to the strength of the effective three-body interaction which, for purposes of explicit calculation, we assume to be spin-independent and of short range.

[1] S. Goldstein and I. Talmi, Phys. Rev. **102**, 589 (1956).
[2] S. P. Pandya, Phys. Rev. **103**, 956 (1956).

WEDNESDAY AFTERNOON AT 4:45

Grand Ballroom

(E. P. WIGNER presiding)

Business Meeting of the American Physical Society

THURSDAY MORNING AT 9:30

North Ballroom

(F. N. FRENKIEL presiding)

Symposium of the Division of Fluid Dynamics Boundary Layer Flow

H1. Some Problems of Unsteady Boundary Layer Flow. C. C. LIN, *M. I. T.* (30 min.)

H2. Boundary Layer Transition Studies at Subsonic Speeds. G. B. SCHUBAUER, *National Bureau of Standards.* (30 min.)

H3. Effects of Extreme Cooling on Boundary Layer Transition at Supersonic Speeds. J. C. EVVARD, *Lewis Flight Propulsion Laboratory.* (30 min.)

H4. Laminar Boundary Layer in a Dissociated Gas. F. R. RIDDELL, *AVCO Research Laboratory.* (30 min.)

Business Meeting of the Division of Fluid Dynamics

(To be held during the session whenever the Chairman chooses.)

THURSDAY MORNING AT 9:30

Grand Ballroom

(V. F. WEISSKOPF presiding)

Invited Papers in Theoretical Physics

HA1. The Nuclear Many-Body Problem. H. A. BETHE, *Cornell University.* (45 min.)

HA2. Shell Model Analysis of Nuclear Energies. I. TALMI, *Princeton University.* (40 min.)

HA3. Stripping Reactions and the Structure of Light Nuclei. J. B. FRENCH, *University of Rochester.* (30 min.)

THURSDAY MORNING AT 9:30

Panel Room

(A. SPERDUTO presiding)

Nuclear Reactions and Nuclear-Energy Levels, I

J1. Interaction of 6-14-Mev Deuterons with Deuterium.* T. M. PUTNAM, J. E. BROLLEY, JR., AND LOUIS ROSEN, *Los Alamos Scientific Laboratory.*—The differential cross sections for the reactions $D(d,n)He^3$, $D(d,p)H^3$, and for D–D elastic scattering have been measured as a function of deuteron energy at 2-Mev intervals between 6 and 14 Mev. The source of deuterons was the Los Alamos Variable Energy Cyclotron. Detection of reaction products was by means of nuclear emulsions in the Los Alamos multiplate camera.[1] The results are based on an analysis of more than 750 000 tracks and comprise over 300 differential cross sections, each obtained to an absolute accuracy of 3–4% (standard error). The two branches of the reaction have essentially identical cross sections between 30 and 90° in the center-of-mass coordinate system. Below 30° the neutron producing branch deviates slightly towards higher cross sections. A second minimum, centered about 90° (c.m.), becomes evident at 12 and 14 Mev. The results of this work will be presented and discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] Allred, Rosen, Tallmadge, and Williams, Rev. Sci. Instr. **22**, 191 (1951).

J2. Differential Cross Sections for $He^3(d,p)He^4$ and the Elastic Scattering of Deuterons from He^3.* VERA KISTIAKOWSKY FISCHER, *Columbia University and Brookhaven National Laboratory.*—Differential cross sections for the $He^3(d,p)He^4$ ground state reaction and the elastic scattering of deuterons from He^3 have been measured with 21-Mev deuterons from the Brookhaven sixty-inch cyclotron. A "turret" type scattering chamber and cylindrical gas target were used. The particles were detected and identified by a thin proportional counter—NaI(Tl) scintillation counter telescope. The angular resolution was ±1.0° in the laboratory system in the case of $He^3(d,p)He^4$ and ±0.5° for $He^3(d,d)He^3$. The $He^3(d,p)He^4$ cross section is 0.72±0.28 mb/sterad at $\theta_{lab}=15°$. Work is continuing to improve the absolute accuracy of the measurement. The angular distribution predicted by Butler stripping theory for a radius of 4.3×10^{-13} cm[1] does not fit the experimental result in detail. The elastic scattering differential cross section shows well-defined maxima and minima. A simple optical model calculation has been undertaken in an attempt to fit the data.

* This work was partially supported by the U. S. Atomic Energy Commission.

[1] Butler and Symonds, Phys. Rev. **83**, 858 (1951).

J3. Scattering of He^3 from He^4 and States in Be^7.* G. C. PHILLIPS AND PHILIP MILLER, *The Rice Institute.*—Scattering measurements for He^3+He^4 have been carried out using helium gas in a differentially pumped gas scattering chamber and a He^{3+} beam from The Rice Institute Van de Graaff accelerator. The laboratory energy range 3 to 6 Mev has been investigated at c.m. He^3 angles of 54°44′, 63°26′, 90°, 116°34′, 109°52′, and 125°16′, and angular distributions have been obtained at laboratory energies of 3.04, 3.95, and 5.28 Mev. A prominent resonance was observed at the laboratory energy of 5.25 Mev and of width 0.28 Mev. This corresponds to a state in Be^7 at 4.58 Mev excitation and of width 0.16 Mev. A preliminary phase shift analysis reveals that the state is $F_{7/2}$, and corresponds well in energy to the $F_{7/2}$ level of Inglis. It is of interest that its reduced width is about 0.31 of the Wigner limit for an F state at this energy and so it is presumably a simple two-particle state of He^3 and He^4. Results of a phase shift analysis will be presented.

* Supported in part by the U. S. Atomic Energy Commission.

J4. Neutrons from the He^3 Bombardment of B^{10}.* F. AJZENBERG-SELOVE, *Boston University and Brookhaven National Laboratory,* M. L. BULLOCK,† *Boston University,* AND E. ALMQVIST, *Chalk River Laboratories.*—A thin B^{10} target[1] has been bombarded with 2.59-Mev He^3 particles at Chalk River. Ilford C-2 emulsions, 400 μ thick, placed at 10 angles (0° to 135°) to the incident beam have been used to measure the neutron spectra. A well-resolved ground-state group ($Q_0=1.46\pm0.06$ Mev) has been observed, as have partially resolved groups, superimposed on a continuous background from $B^{10}(He^3,np)C^{11}$ ($Q=0.98\pm0.04$ Mev), corresopnding to at least four excited states of N^{12} with $E_X<2.6$ Mev. The location of the levels are in good agreement with those in the mirror nucleus, B^{12}. The angular distribution of the ground state neutrons is essentially isotropic. The "total" cross section for formation of the ground state of N^{12} is 5±2 mb. The mass of N^{12} is calculated to be 12.02254±0.00008 amu. The atomic mass excess, $M-A$, is then 20.99±0.07 Mev.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command and by the U. S. Atomic Energy Commission.

† Now at I.B.M. Corporation, Boston.

[1] Supplied by Dr. M. L. Smith of the Atomic Energy Research Establishment, Harwell, England.

J5. Reaction $Li^7(\alpha,\gamma)B^{11}$.* LUISE MEYER-SCHÜTZMEISTER AND S. S. HANNA, *Argonne National Laboratory.*—Gamma-ray angular distributions and correlations have been measured in

the $Li^7(\alpha,\gamma)B^{11}$ reaction. A rotating lithium target was irradiated with an alpha beam of about 12 μa. The gamma rays were detected with a 3.5-in. NaI crystal. In the expression $1+A_2\cos^2\theta$, the following values of A_2 have been measured in the angular distribution experiments.

Gamma ray Mev	960 kev	Resonance 820 kev	400 kev
9.0	-0.47 ± 0.04	-0.20 ± 0.05	-0.20 ± 0.04
6.81	0.44 ± 0.12	0.36 ± 0.08	
4.5	$\geqslant 1.25$	$\geqslant 0.36$	
4.46	$\leqslant 0.26$	$\leqslant -0.30$	
5.03			$\geqslant 0.45$

The interpretation of these results in terms of the spin and parity of the levels in B^{11} will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

J6. $Li^7(p,\alpha)He^4$ Reaction at 15 and 18.5 Mev.* D. R. Maxson and H. Horie,† *Princeton University.*—Likely and Brady[1] have found that for 18.5-Mev protons the angular distribution of alpha particles from the reaction $F^{19}(p,\alpha)O^{16}$ is consistent with the assumption of a triton pickup process, in which a triton is exchanged between the target nucleus and the incident proton. These measurements have been extended to see if (p,α) reactions in other light nuclei may proceed by a similar mechanism. In the present experiment, angular distributions and absolute differential cross sections of the $Li^7(p,\alpha)He^4$ reaction were observed at bombarding energies of 15.0 ± 0.1 and 18.55 ± 0.1 Mev. The angular distributions are similar at the two energies, with a maximum at small angles and a broad peak centered between 50 and 60° (c.m.). The cross section at the peak is 1.6 ± 0.2 mb/sterad at 15 Mev and 1.3 ± 0.1 mb/sterad at 18.55 Mev. Calculated triton-pickup angular distributions are extremely sensitive to the choice of the interaction radius and are not adequate to fit the data, although qualitative agreement is obtained with $R=4.45\times10^{-13}$ cm.

* This work was supported by the U. S. Atomic Energy Commission and the Higgins Scientific Trust Fund.
† Now at Tokyo Institute of Technology, Tokyo, Japan.
[1] J. G. Likely and F. P. Brady, Phys. Rev. **104**, 118 (1956).

J7. $C^{12}(\alpha,p)N^{15}$ Reaction at 41.5 Mev.* R. Sherr,† *Princeton University,* and M. Rickey, *University of Washington.*—As the inverse of the (p,α) reaction described in the preceding abstract (Maxson and Horie), the (α,p) reaction in the same energy range should exhibit a similar type of angular distribution. The $C^{12}(\alpha,p)N^{15}$ reaction has been investigated using the 41.5-Mev α particle beam of the University of Washington cyclotron. In addition to the ground state, protons corresponding to many (unresolved) excited states were seen up to an excitation of 13.5 Mev; all showed nonisotropic angular distributions. For ground state pronounced maxima were found at 0°, 45°, 85°, and 150° (c.m.) with cross sections of 1100, 100, 36, and 18 mb/sterad, respectively. Assuming stripping with l(triton) = 1, and $R=5.10\times10^{-13}$ cm, an excellent fit to the data is obtained for angles greater than 30°. At smaller angles the observed cross sections increase much more than the predicted values and near 0° are 14 times as great.

* Supported in part by the U. S. Atomic Energy Commission.
† Summer visitor at the University of Washington, 1956.

J8. Measurement of Cross Section of $Be^9(n,\alpha)He^6$. E. C. Campbell and P. H. Stelson, *Oak Ridge National Laboratory.*—The cross section for the reaction $Be^9(n,\alpha)He^6$ (0.8 sec) was measured by detecting the β decay of He^6 for neutron energies up to 4.4 Mev. Square-wave modulation of the (p,n) neutron source together with synchronous gating of the anthracene β detector eliminated counts due to fast neutrons. The cross section exhibits a smooth rise from less than 10 μb at the expected threshold of 0.7 ± 0.05 Mev to a peak of 100 ± 10 mb at 3.0 Mev, followed by a decrease to 60 mb at 4.4 Mev. The absolute neutron flux was determined with a U^{238} fission chamber to an accuracy of $\pm6\%$. The β-counting efficiency is known to $\pm5\%$.

J9. Breakup of Be^{9*} (2.43-Mev) Using Coincidence Technique.† D. Bodansky, S. F. Eccles, and I. Halpern, *University of Washington.*—Observation of inelastically scattered 42-Mev alpha particles from a Be target provides a means for selecting events in which the excitation energy and laboratory momentum of recoiling Be^{9*} nuclei are determined. The breakup from the Be^9 2.43-Mev level was studied by observing the angular and energy distributions of charged decay products, in coincidence with the scattered alpha particles. The latter were selected in a plastic—CsI phoswich[1] placed at a convenient angle (60°). Possible decay modes are to (1) Be^8+n, $Be^8\rightarrow He^4+He^4$; (2a) He^4+He^5, $He^5\rightarrow He^4+n$; (2b) He^4+He^4+n; and (3) $Be^9+\gamma$. Only about 25% of the breakup alpha particles fall within the relatively tight momentum interval kinematically allowed to mode (1). This 25% provides a liberal upper limit on the probability of decay via mode (1) as a substantial fraction of this group may be due to mode (2). The observed scarcity of appropriate recoiling Be^9 nuclei indicates an upper limit for (3) of 1%. This technique is being applied to other decay problems.

† Supported in part by the U. S. Atomic Energy Commission.
[1] D. H. Wilkinson, Rev. Sci. Instr. **23**, 414 (1952).

J10. Lifetimes of the 4.4-Mev Excited States of B^{11} and C^{12}.* C. P. Swann, F. R. Metzger, and V. K. Rasmussen, *Bartol Research Foundation.*—$N^{15}H_3$ gas was bombarded by 3.4-Mev protons from the Bartol-ONR electrostatic accelerator. This gives a copious source of Doppler-broadened 4.43-Mev gamma rays from the first excited state of C^{12}. The scattering of these gamma rays by graphite and by lithium nitrate has been observed, the difference being attributed to nuclear resonance fluorescence in C^{12}. The self-absorption of the resonance radiation also was observed by interposition of graphite and lithium nitrate absorbers between the source and the graphite scatterer. From this, the lifetime of the first excited state of C^{12} is found to be $(7\pm2)\times10^{-14}$ sec. The scattering of the same gamma radiation by boron carbide and lithium nitrate has also been observed, the difference being attributed to nuclear resonance fluorescence in B^{11}. Assuming a spin of 5/2 for the 4.46-Mev second excited state of B^{11}, the lifetime of this state is found to be $(1.0\pm0.2)\times10^{-15}$ sec.

* Assisted by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

J11. Inelastic Scattering of Protons from C^{13}.* L. J. Lidofsky, J. Weil, R. D. Bent, and K. W. Jones, *Columbia University.*—The excitation function for γ radiation from inelastic scattering of protons on C^{13} has been determined for proton bombarding energies up to 6.40 Mev. Resonances appear in the yield at 90° for $E_p=5.381\pm0.007$ Mev and 5.930 ± 0.007 Mev corresponding to excited states in N^{13} at $E^*=6.912$ ($\Gamma\sim0.130$) Mev and $E^*=7.419$ ($\Gamma\sim0.085$) Mev. The peak cross section at 5.93 Mev is 8 mb/sterad at 90° normalized to the peak cross section at the 5.38-Mev resonance as quoted by Reich *et al.*[1] The angular distribution relative to the proton beam was measured at ~100 kev intervals from $E_p=5.38$ to 6.40 Mev. At $E_p=5.9$ Mev the angular distribution was consistent with an assignment of $5/2^+$ to the 7.419-Mev state.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Reich, Phillips, and Russell, Phys. Rev. **104**, 143 (1956).

J12. Search for Electric Monopole Pair Transitions in C^{13} and Ca^{40} Using a Scintillation Pair Spectrometer.* T. H. Kruse, R. D. Bent, and K. E. Eklund, *Columbia University.*—If the 7.65 and 3.82-Mev states of C^{13} and Ca^{40}, respectively, are 0^+, they should decay to the ground states chiefly with

the emission of electron pairs. A three-crystal pair spectrometer was modified for detecting electron pairs by replacing the center NaI crystal with a "well" plastic scintillator. Targets are placed near the bottom of the well and the electron pairs are detected with almost 4π geometry. This spectrometer gives 13% resolution for the 6.05-Mev pair line from the $F^{19}(p,\alpha\pi)O^{16}$ reaction and is calculated to be about 250 times more efficient for electron pairs than for 4.43-Mev gamma rays. No 7.6-Mev pair line was detected from the $Be^{9}(\alpha,n)C^{12}$ reaction ($E_\alpha = 5.6$ Mev, thick target). The yield of pairs was less than 6×10^{-6} that of 4.43-Mev gamma rays. A preliminary search has been made for 3.82-Mev pairs from the $Ca^{48}(p,p')$ reaction ($E_p = 5.5-6.3$ Mev) using a $CaCO_3$ target (62% Ca^{48}, 35% Ca^{40}). No strong 3.82-Mev pair line has been observed. A weak line would have been obscured by the high-energy tail of the 3.35-Mev line from the $Ca^{40}(p,p')$ reaction. The $Ca^{48}(p,p')$ reaction is expected to be relatively weak because of the competing (p,n) reaction.

* This work was partially supported by the U. S. Atomic Energy Commission.

THURSDAY MORNING AT 9:45

Terrace Room

(S. MILLMAN presiding)

Magnetic Resonance I

JA1. Atomic Hyperfine Structures of Cs^{137} (6.2 hr) and Cs^{139} (31 hr).* HENRY B. SILSBEE, WILLIAM A. NIERENBERG, HOWARD A. SHUGART, AND ROBERT J. SUNDERLAND, *University of California, Berkeley.*—Because of the unexpected spin of $I = \frac{7}{2}$ for both Cs^{137} and Cs^{129}, values of the hyperfine structure separations are of interest.[1] Measurements of the hyperfine structure separations for these isotopes have been made by observing transitions between the $F = I+\frac{1}{2}$, $m = -(I-\frac{1}{2})$, and $m = -(I+\frac{1}{2})$ states at various magnetic fields in an atomic beam "flop-in" apparatus. Assuming a positive value for the magnetic moments, Cs^{137} gives a hyperfine structure of 8790 ± 250 Mc/sec, and Cs^{129} gives 9190 ± 260 Mc/sec. With Cs^{133} as a reference, the Fermi-Segrè formula predicts from these measurements the nuclear magnetic moments: Cs^{137}, $\mu = +1.41\pm0.04$; Cs^{129}, $\mu = +1.47\pm0.04$ nuclear magnetons. Since both isotopes have the same spin and about the same hyperfine structure separation, an experimental resonance curve must be analyzed into the two component resonance curves by observing the decay of each resonance point. Although not yet definitely established, a positive sign for the nuclear moment appears more consistent with the experimental evidence than does a negative sign.

* Work supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

[1] Nierenberg, Shugart, Silsbee, and Sunderland, UCRL-3487 (1956) (to be published).

JA2. Some Moments of Radioactive Iodine Nuclei.* P. FLETCHER AND E. AMBLE, *Columbia Radiation Laboratory* (introduced by C. H. TOWNES).—Approximately 1 μg of I^{126} has been obtained by bombardment of tellurium by deuterons [$Te^{124}(d,2n)I^{125}$ and $Te^{124}(dn)I^{125}$] and chemically synthesized into CH_3I^{126}. The absorption spectra of this molecule was then examined with a conventional stark modulated microwave spectrometer. Five absorption lines have been observed which can be fitted into a quadrupole hyperfine structure pattern of the $J = 2\leftarrow1$ rotational spectrum assuming a nuclear spin for the I^{126} of 5/2. The resulting quadrupole coupling constant is 2179.5 ± 1.0 Mc, giving a ratio of quadrupole moments $Q_{126}/Q_{127} = 1.1270\pm0.0005$. The shift of the rotational frequency due to the isotopic substitution of I^{126} was 49.3 ± 5 Mc in good agreement with that expected. The observed values of spin and quadrupole moment suggest a $d_{5/2}$ configuration for the ground state of the I^{126} nucleus similar to that of I^{127}. Preliminary measurements on the magnetic moment of I^{126} by Zeeman effects on the microwave spectrum also indicate this configuration. This technique is also being applied to determine the moments of other radioactive iodine nuclei.

* Work supported in part by the U. S. Atomic Energy Commission and in part jointly by the Signal Corps, the Office of Naval Research, and the Air Research and Development Command.

JA3. Zeeman Splitting of Nuclear Quadrupole Energy Levels in a Single Cuprite Crystal.* HENRY L. COX, JR., AND DUDLEY WILLIAMS, *Ohio State University.*—Two absorption lines, with frequencies near 26 Mc and 24 Mc, have been observed in earlier studies[1] of cuprous oxide and have been attributed to nuclear quadrupole transitions involving Cu^{63} and Cu^{65}, respectively. The present work involves the behavior of corresponding lines in a single cuprite crystal when an external magnetic field is superposed on the internal electric field. From the results obtained experimentally at 28°C, the following parameters have been determined:

$$eqQ^{63} = 51.96\pm0.04 \text{ Mc}$$
$$eqQ^{65} = 48.06\pm0.04 \text{ Mc}$$
$$\mu^{63} = 2.226\pm0.007 \text{ nm}$$
$$\mu^{65} = 2.376\pm0.007 \text{ nm}$$
$$\eta < 0.0015.$$

These results will be compared with values obtained by other methods.

* This work has been supported by a contract between the Office of Scientific Research of the Air Research and Development Command.

[1] H. Kruger and U. Meyer-Berkhout, Zeits Phys. 132, 171 (1952).

JA4. U^{235} and U^{233} Nuclear Quadrupole Coupling in the UO_2^{++} Group from Specific Heat Measurements. L. D. ROBERTS, J. W. T. DABBS, AND G. W. PARKER, *Oak Ridge National Laboratory.*—In order to interpret results[1] on the anisotropic emission of α particles from aligned U^{233} nuclei, it was necessary to determine the magnitude of the quadrupole coupling producing the alignment. These results indicated a splitting sufficiently large to give an observable Schottky specific heat in the temperature region below 1°K. Direct specific heat measurements for this purpose have been performed on $U^{235}O_2F_2$ between approximately 0.3° and 0.8°K. A paramagnetic salt and an electrical resistance heater were connected thermally to the UO_2F_2 sample. The paramagnetic salt served as both coolant and thermometer. Assuming a spin hamiltonian $\mathcal{H} = Q(I_z^2 - I(I+1)/3)$, the molar specific heat at sufficiently high temperatures is given by $C/R = h^2c^2Q^2I(I+1) \times[4I(I+1)/3-1]/15k^2T^2$, where Q is cm^{-1}. Preliminary measurements give $Q(U^{235}) = -0.015\pm0.002$ cm^{-1}. The sign of the coupling is based on theoretical considerations of Eisen-

stein and Pryce.[1] This experiment cannot be performed using U^{233} because of the heating from the high specific α activity. However, a value for $Q(U^{233})$ may be obtained using the quadrupole moment ratio recently obtained by Dorain, Hutchison, and Wong (unpublished).

[1] Roberts, Dabbs, Parker, and Ellison, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956); Dabbs, Roberts, and Parker, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956).

JA5. α-Particle Anisotropy from Aligned U^{233} Nuclei. J. W. T. Dabbs, L. D. Roberts, and G. W. Parker, *Oak Ridge National Laboratory.*—The previous measurements[1] on the anisotropic emission of α particles from aligned U^{233} nuclei have been extended using a new apparatus. The salt used was $UO_2Rb(NO_3)_3$. More accurate angular distributions as a function of temperature have been obtained and may be described by $W(\theta,T)=1+(A_2/T)P_2(\cos\theta)$ with $A_2=-0.063\pm0.002$, θ measured from the crystalline c axis, and T in °K. This result, together with the quadrupole coupling determination of the preceding abstract, permits an analysis of the anisotropy in terms of angular momentum theory (Rose *et al.*[2]) and the interpretation of the U^{233} α-particle fine structure by Bohr, Froman, and Mottelson.[3] The latter authors present arguments suggesting that only S and D waves are important in the α-particle emission. Under this assumption, the analysis indicates that the S and D waves in the ground state transition are of approximately equal amplitudes and of opposite sign.

[1] Roberts, Dabbs, Parker, and Ellison, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956); Dabbs, Roberts, and Parker, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956).
[2] Rose, Roberts, and Dabbs, Bull. Am. Phys. Soc. Ser. II, 1, 207 (1956).
[3] Bohr, Froman, and Mottelson, Dan. Mat. Fys. Medd. 29, No. 10 (1955).

JA6. The Quadrupole Moment of O^{17}.* M. J. Stevenson,† *Columbia University.*—The nuclear quadrupole hyperfine structure resulting from O^{17} has been measured by A. H. Nethercot, Jr., and B. Rosenblum[1] in the rotational microwave spectrum of the molecule CO^{17}. They find a quadrupole coupling constant eqQ which is positive in sign and appreciably larger than that found in OCS.[2] Since neither its sign nor its magnitude can be reconciled with the present value of the quadrupole moment Q of O^{17} and accepted electronic structure of CO, the microwave spectrum of HDO^{17} is being investigated. Hyperfine structure in the rotational transition 2_{20}←2_{21} has been observed. Its analysis should yield a determination of the quadrupole moment of O^{17} with more certainty than is allowed by the spectrum of OCS or CO because of the relative simplicity in the evaluation of field gradients from the electronic structure of HDO.

* Work supported jointly by the Signal Corps, the Office of Naval Research, and the Air Research and Development Command.
† John Tyndall Fellow.
[1] Private communication.
[2] Geschwind, Gunther-Mohr, and Silvey, Phys. Rev. **85**, 474 (1952).

JA7. Hyperfine Structure Anomaly (HFSA) of Sb^{121} and Sb^{123} Measured by the Electron Spin Double Resonance Method (ESDR). J. Eisinger and G. Feher, *Bell Telephone Laboratories.*—The HFSA, Δ, reflects the difference in nuclear size and in the distribution of the nuclear magnetic dipole moments between isotopes of the same element.[1] For the two Sb isotopes Δ is given by $(a_{121}/a_{123})=(g_{121}/g_{123})(1+\Delta)$ where a is the hyperfine interaction constant and g is the nuclear g factor. Δ has been calculated from ratios of a's obtained from atomic beam experiments for several nuclei and the results have been compared with theory.[1] We have measured the a-ratio by performing an electron spin resonance experiment on Sb doped silicon at 9000 mc/sec. (a_{121}/a_{123}) was obtained by two methods: one involves the precise determination of the HFS in the applied field and the other is based on the ESDR technique.[2] The latter is more accurate and moreover yields a value for (g_{121}/g_{123}) which is of comparable accuracy and in agreement with the NMR value. In this way we obtain $\Delta=-(0.354\pm0.006)\%$. A simple single-particle model based on Sb^{121} and Sb^{123} having odd protons in the $d_{5/2}$ and $g_{7/2}$ states, respectively, yields $\Delta=-0.41\%$.

[1] A. Bohr and V. F. Weisskopf, Phys. Rev. **77**, 94 (1950).
[2] G. Feher, Phys. Rev. **103**, 834 (1956).

JA8. Effect of Exchange Interactions on Nuclear Hyperfine Structure in Paramagnetic Resonance Spectra. D. Kivelson, *University of California at Los Angeles and Columbia University.*—Fermi contact interactions between nuclear and electronic moments give rise to hyperfine lines in the electron spin resonance spectra of substances. This hyperfine structure is strongly affected by electronic spin exchange interactions. Anderson[1] has shown that these interactions modulate the remaining terms in the Hamiltonian and that the exchange terms can be treated by stochastic methods. Kubo and Tomita[2] have developed a theory based upon time dependent perturbation theory which includes the nonsecular terms omitted by Anderson. The present analysis is based upon this latter theory and is analogous to the work of Yokota and Koide[3] on the effect of exchange interactions on the fine structure arising from the anisotropic nature of the g tensor in crystals. Exchange frequencies both large and small compared to the hyperfine separations are treated. As expected, the hyperfine lines broaden and start to coalesce as the exchange frequency increases, and then narrow down to a single line for very large exchange interactions.

[1] P. W. Anderson, J. Phys. Soc. Japan **9**, 316 (1954).
[2] R. Kubo and K. Tomita, J. Phys. Soc. Japan **9**, 888 (1954).
[3] M. Yokota and S. Koide, J. Phys. Soc. Japan **9**, 953 (1954).

JA9. Paramagnetic Resonance Spectrum of V^{49}.* Max M. Weiss,† Robert I. Walter,‡ O. R. Gilliam,§ and V. W. Cohen, *Brookhaven National Laboratory.*—We have studied the paramagnetic resonance spectrum in xylene solution of a vanadium (IV)-cupferron chelate prepared from a sample containing V^{49}. The ratio of V^{49} to V^{51} was of the order of one part in 200. The large amount of V^{51} was present as an impurity in the titanium from which the V^{49} was prepared by deuteron bombardment. The hyperfine pattern of the spectrum was examined and showed two very weak components consistent with magnetic quantum number assignments of $+5/2$ and $+7/2$, respectively. The lower m components could not be resolved from the V^{51} lines. If a 9/2 component had been present it would have been clearly visible. These results are consistent with a V^{49} spin assignment of 7/2 and a magnetic moment ratio of $\mu^{(49)}/\mu^{(51)}$ of 0.867 ± 0.01. Further work is in progress to prepare a sample of higher ratio of V^{49} to V^{51} contents so that a clearer spectrum might be observed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Now at Bell Telephone Laboratories, Whippany, New Jersey.
‡ Now at Haverford College, Haverford, Pennsylvania.
§ Permanent address: University of Connecticut, Storrs, Connecticut.

JA10. A Possible Transient Overhauser Effect in a Silica Containing Protons. G. R. Holzman, John H. Anderson, and W. Koth, *Mellon Institute.*—(a) While a fused silica[1] (T_1 of Si = 10 hr) is soaked in a 9.4 kilogauss field for 5 minutes, the Si^{29} energy levels are saturated by rf power. (b) The sample is removed to the earth's field for 45 seconds and then reinserted into the high field. (c) A rapid passage nuclear magnetic resonance experiment is performed. A silicon moment having the same direction and equal in magnitude to about $\frac{1}{2}$ the equilibrium 9.4 kilogauss field value is then observed. Repeat experiments with varying high field soaking periods give a plot of signal amplitude *vs* time. From this roughly exponential curve, a relaxation time of 3 minutes can be calculated. To learn whether the Si^{29} spins relax via their interaction with proton impurities, an effort was made to saturate the hydrogen levels in step (a). A repeat of (b) and (c) gave zero or very little Si^{29} signal. An examination of the general solution

to Solomon's[2] equation of motion for the Si^{29} moment suggests that the phenomenon may be a transient Overhauser effect.

[1] Holzman, Anderson, and Koth, Phys. Rev. **98**, 542 (1955).
[2] I. Solomon, Phys. Rev. **99**, 559 (1955).

JA11. Nuclear Polarization and Associated Specific Heat in Metals at Low Temperatures. W. A. BARKER AND E. A. DESLOGE, *St. Louis University.*—It has been shown that a high nuclear polarization may be achieved in metals at low temperatures by saturation of the conduction electron spin resonance.[1] We have calculated an expression for the contribution to the specific heat due to this steady state nuclear polarization. The theoretical curve of C_{H_0} *vs* H_0/T for a given nuclear spin I goes through a maximum. As I is increased, this maximum increases and occurs at smaller H_0/T values. In the absence of a time varying magnetic field (i.e., zero saturation of the electron spin resonance), our expression reduces to its known thermal equilibrium form.[2] In Li^7, assuming complete saturation of the electron spin resonance, $(C_{H_0})_{max}=4.4\times10^{-4}R$ for $H_0=10^4$ oersted and $T=0.88°K$. This corresponds to a nuclear polarization of 83%. Additional numerical data for other metals will be presented.

[1] A. W. Overhauser, Phys. Rev. **92**, 411 (1953); T. P. Carver and C. P. Slichter, Phys. Rev. **92**, 212 (1953); W. A. Barker and A. Mencher, Phys. Rev. **102**, 1023 (1956).
[2] Norman F. Ramsey, Phys. Rev. **103**, 20 (1956).

THURSDAY MORNING AT 9:30

Boston-Washington Room

(J. RAINWATER presiding)

Medium-Energy Scattering and Neutron Physics

K1. Timing Scheme for a Time-of-Flight Neutron Spectrometer.* MIGUEL AWSCHALOM, *Louisiana State University.*—A timing system for measurements of time of flight in a neutron spectrometer will be described. The detection of the neutrons with a hydrogenous detector and associated fast electronic circuitry for pulse shaping and sorting is the conventional one for this kind of work. However, the device to measure the time of flight is uncommon.[1] It consists of (1) a CRT swept in a circular fashion by the same precision oscillator[2] used for bunching the neutron generating ion beam[3]; (2) z-axis modulation of the CRT by the fast pulses from the detector; (3) a bank of 120 photomultiplier tubes arranged in a circular pattern and monitoring the face of the CRT through a focusing lens; (4) a system of "slow" discriminators and gates (one for each photomultiplier) to extract the proper information from the bank of photomultipliers. With a sweep frequency of 8.8 Mc/sec, a time resolution of the order of one millimicrosecond is expected.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] M. Awschalom, October 8, 1955 (not published).
[2] R. C. Mobley and B. R. Albritton, Phys. Rev. **98**, 232 (1955).
[3] R. C. Mobley, Phys. Rev. **88**, 360 (1952).

K2. Angular Distributions of Inelastic Neutrons from 14-Mev Neutron Scattering.* M. P. NAKADA, J. D. ANDERSON, C. GARDNER, AND C. WONG, *University of California, Livermore.*—Absolute differential cross sections have been measured for the inelastic scattering of 14-Mev neutrons. A pulsed source time-of-flight technique was used with ring scatterers. The cross sections and energies were converted to the center-of-mass coordinate system. $I(\theta)$, the integral of the differential cross section, was evaluated from 1.5 to 4 Mev. The following preliminary values of $I(\theta)$ have been obtained for lead: 30°, 269±10 mb/sterad; 40°, 229±5; 60°, 206±5; 80°, 201±5; 100°, 191±4; 120°, 204±4; 140°, 199±4. Because of the large forward peaking of these neutrons, $I(\theta)$ was also evaluated from 1.5 to 2 Mev. Similar forward peaking of neutrons was exhibited. Al, Fe, Sn, and Bi all showed forward peaking of similar amounts. Preliminary $I(90°)$ from 1.5 to 4 Mev for these elements are: 32±1 mb/sterad, 51±1, 105±4, and 190±3, respectively.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

K3. New Technique for Measuring Gamma Rays from Neutron Inelastic Scattering.* ROBERT B. DAY AND DAVID A. LIND, *Los Alamos Scientific Laboratory.*—In many experiments on the gamma rays excited by neutron inelastic scattering the major part of the background has arisen from neutron interactions within the NaI(Tl) crystal used as the gamma-ray detector. In order to reduce this background, a new technique has been developed that uses time of flight to distinguish between neutrons and gamma rays. A pulsed neutron source is produced by the beam deflection method used by Cranberg and Levin. These neutrons bombard a suitable scatterer and the resultant gamma rays are detected by a NaI scintillation counter 18 cm from the scatterer. The repetition rate of the pulsed neutron source is 2×10^7/sec. After each neutron pulse the output of the NaI counter is examined to see whether the counter has produced a pulse at a time corresponding to the time of arrival of a gamma ray produced by inelastic scattering in the scatterer. If the answer is yes, a pulse-height analyzer is gated on to analyze the height of the pulse. The over-all time resolution obtainable varies from 2 mμsec at a gamma-ray energy of 500 kev to 6 mμsec at 70 kev; however, the required separation of neutron-induced background from the gamma rays of interest can usually be obtained at poorer resolution, where higher counting rates can be obtained.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

K4. Elastic Neutron Scattering from Alpha-Particle Nuclei. J. L. FOWLER AND H. O. COHN, *Oak Ridge National Laboratory.*—The nonresonant neutron differential elastic scattering cross sections for oxygen and beryllium have been measured as a function of angle at several energies by the technique of detecting scattered neutrons with a shielded recoil counter. For oxygen the data together with other measurements reported in the literature allow one to estimate the scattering phase shifts in the 0–2 Mev energy range. In this range the s-wave potential scattering phase shifts vary smoothly with energy and can be calculated from a static potential well. If one also requires that the energy position of the $J=\frac{1}{2}^+$ bound state of O^{17} be correctly given by the well, the parameters are determined for any given shape. Analysis of the literature scattering data for C^{13} and use of the bound s level in C^{13} in the same manner give a similar potential well for a neutron due to the C^{13} core. In order to make the effective radius of the potentials change in the expected way in going from C to O, one must introduce a diffuse boundary to the well. The elastic neutron

scattering from He^4 has been calculated[1] with the same type wells.

[1] E. Van der Spuy, Nuclear Phys. **1**, 381 (1956).

K5. $(n,2n)$ Cross Sections for 14-Mev Neutrons on Be, Ta, and Bi.* LEONA STEWART AND LOUIS ROSEN, *Los Alamos Scientific Laboratory.*—Nuclear emulsion detectors were used to determine the space-integrated neutron spectrum from the interaction of 14-Mev neutrons on the above elements. On the assumption that particle emission, where energetically possible, precludes de-excitation by gamma emission, one arrives at $(n,2n)$ cross sections of 0.4, 1.8, and 2.3 barns for Be, Ta, and Bi, respectively. $\sigma(n,2n)$ for Be agrees with theoretical predictions of Sachs[1] but not with the theory of Mamasakhlisov[2] which probably does not apply to this high an energy region. In the case of Bi there is good agreement with independent $(n,2n)$ measurements.[3] The nonelastic cross sections of 0.4, 2.0, and 2.4 barns, which were obtained in the same manner, correspond reasonably well to those previously reported.[3,4]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Mendel Sachs, Phys. Rev. **103**, 671 (1956).
[2] V. I. Mamasakhlisov, Zhur. Eksptl. i Teoret. Fiz. **25**, 36 (1953).
[3] E. R. Graves and R. W. Davis, Phys. Rev. **97**, 1205 (1955).
[4] Taylor, Lönsjö, and Bonner, Phys. Rev. **100**, 174 (1955).

K6. Inelastic Neutron Scattering in Rh and Nb.* M. A. ROTHMAN, D. M. VAN PATTER, V. S. DUBEY, W. C. PORTER, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Gamma rays from inelastic neutron scattering in rhodium and niobium have been studied. In rhodium 300- and 365-kev gamma rays have been observed, while in niobium 740- and 950-kev gamma rays were excited. Excitation curves and cross sections have been obtained for these gamma rays. The thresholds of these excitation curves are being measured accurately to give an unambiguous level scheme.

* Assisted by the U. S. Atomic Energy Commission.

K7. Neutron Resonances in Even-Even Nuclei.* F. P. KARRIKER, H. MARSHAK, AND H. W. NEWSON, *Duke University.*—Neutron total cross sections have been measured from about 5 to 200 kev for Ti, Cr, Cr^{50}, Cr^{52}, Cr^{54}, Fe^{54}, and Fe. Effective sample thicknesses were 2.67, 3.00, 2.27, 2.19, 1.66, 2.0, and 5.0 atoms/cm^2, respectively. The number of definite resonances found on each cross-section curve were 5, 4, 6, 4, 6, 5, and 8, respectively. A level in natural iron at 9 kev appears to be due entirely to Fe^{54}; the rest of the resonances observed in the natural elements must all be due principally to the predominant isotopes: Ti^{48}, Cr^{52}, and Fe^{56}. The apparent level density is about the same between 0 and 100 as between 100 and 200 kev. Preliminary determinations of the widths of the levels below 200 kev indicate an approximately exponential distribution of reduced widths. Lumping together the resonances of Ti^{48}, Cr^{50}, Cr^{52}, and Fe^{54} one obtains an average strength function, $(\Gamma_n^0/D) = 3.5\times10^{-4}$, assuming that all resonances are due to s neutrons. This is in good agreement with the value 3×10^{-4} found by Marshak and Newson by averaging over transmission curves for Sc^{45}, V^{51}, and Mn^{55}. Coincidences in energy between the resonances observed in isotopes are far more frequent than the other coincidences observed. In Ti^{48} there is a resonance at 18 kev with a measured half-width of 8 kev which is far greater than any reasonable estimate of neutron energy spread.

* This work was supported in part by the U. S. Atomic Energy Commission.

K8. Assignment of Neutron Resonance Parameters.* P. W. CRUTCHFIELD, W. HAEBERLI, AND H. W. NEWSON, *Duke University.*—The following resonances have been remeasured: F(27), F(49), F(100), Na(53), Al(36), and Al(88); the neutron energy in kev is shown in parenthesis after the symbol for the element. The measurements were made with several sample thicknesses. For the thinnest sample used in each case, the observed peak cross sections, σ_0(exp), were 25, 25, 18, 16, 22.5, and 16.0 barns, respectively. Correcting for background and resolution the experimental values agree fairly well with the theoretical values, 122, 41, 20, 44, 31, and 17.5, respectively, which correspond to the assignments (J^π): 2^-, 1^-, 1^-, 3^-, 2^+, and 3^+ ($^\pm$ refers to the parity of the neutron wave). However, the assignment may be considered definite only in the cases where the corrections are small, since they must be based on estimates of background, neutron width, and neutron energy spread. The Al resonances appeared to be almost perfectly resolved with observed widths at half theoretical maximum, $\Gamma = 12$ kev for Al(88), and $\Gamma = 3$ kev for Al(53); sample thicknesses were 1.90 and 3.81×10^{22} atoms/cm^2. Area analysis of the Na(53) peak (sample thicknesses, 2.41×10^{22} atoms/cm^2) indicated a width of 0.8 kev, assuming $J = 3$; the peak was symmetric indicating a p-wave neutron.

* This work was supported in part by the U. S. Atomic Energy Commission.

K9. Self-Detection Method for Studying Neutron Resonances.* E. MERZBACHER, *University of North Carolina,* AND H. W. NEWSON AND P. W. CRUTCHFIELD, *Duke University.*—In column 3 of Table I $\sigma_0(d) = (1/N)\ln(I_0 - I_N)/(I_N - I_{2N})$

TABLE I.

	$\sigma_0(C)(J^\pi)$	$\sigma_0(d)$	$\sigma_0(C)(J^\pi)$	Γ/Δ kev
Al(36)	30(2$^+$)	29	40(3$^+$)	3/1.8
Na(53)	27(3$^-$)	27	22(2$^-$)	0.8/2.1
F(49)	39(1$^-$)	37	47(2$^-$)	1.4/2.1
F(27)	52(2$^-$)	59	29(1$^-$)	0.3/1.5

barns is the peak total resonance cross section measured by a self-detection method; I_0, I_N, and I_{2N} are the experimental neutron counts (after correction for potential scattering) transmitted through thicknesses of 0, N, and $2N$ atoms/cm^2, respectively. $\sigma_0(d)$ is subject to no background and much less resolution correction than σ_0(exp), but the statistical error is considerably worse. $\sigma_0(C)$ in column 2 is calculated by making a resolution correction based on the values of J^π (in column 2) and of Γ/Δ (Δ is the neutron energy spread) in column 4 and substituting the calculated transmissions into the above equation for $\sigma_0(d)$. The values for $\sigma_0(C)J^\pi$ in column 2 were obtained from the assignments of the previous abstract; comparing $\sigma_0(d)$ with $\sigma_0(C)$, it appears that the corrections are small compared to those in the previous abstract. It should be noted that, if a larger neutron energy spread is assumed, impossible assignments (i.e., reduced widths exceeding the Wigner limit) are indicated for F(27) and Na(53).

* This work was supported in part by the U. S. Atomic Energy Commission.

K10. Energy Dependence of Elastic Scattering of Protons from V, Cr, Fe, and Co.* CHARLES A. PRESKITT, JR., *University of Rochester.*—The Rochester variable energy cyclotron has been used to measure the angular distribution of protons elastically scattered from V, Cr, Fe, and Co over the energy range of 4.0 to 6.5 Mev. The method used was similar to that of Wall and Waldorf[1] and yields a direct measurement of the ratio of the cross section to the Coulomb scattering cross section with an accuracy that is independent of angle. The ratios σ/σ_{coul} for vanadium and cobalt are very similar and show slow and regular changes with energy. The data for chromium and preliminary data for iron shows no such regular behavior. In particular, the region in chromium from 5.0 to 5.5 Mev and in iron from 5.3 to 6.3 Mev shows large changes

in $\sigma/\sigma_{\text{coul}}$ for energy changes of 100 kev. At the present time this work is being extended to both higher and lower energies.

* This work was supported by the U. S. Atomic Energy Commission.
[1] N. S. Wall and W. F. Waldorf, Bull. Am. Phys. Soc. Ser. II, 1, 212 (1956).

K11. Elastic Scattering of Protons from Si^{28}.* J. VORONA, J. W. OLNESS, W. HAEBERLI, AND H. W. LEWIS, *Duke University.*—The differential cross section for the elastic scattering of protons by Si^{28} has been measured at the four laboratory angles, 167.2°, 140.0°, 88.0°, and 53.1° with bombarding energies ranging from 1.40 to 3.80 Mev. The proton beam energy was determined to 0.1% by a 90° cylindrical electrostatic analyzer. The target gas, silane (SiH_4), was prepared by adding Mg_2Si to dilute HCl and fractionating the gaseous reaction products. Special care had to be used in the preparation and use of this gas since it is spontaneously explosive in air. The silane was sealed in the scattering chamber by a thin Al_2O_3 foil (about 2000 A°). These foils were prepared by oxidizing one surface of a 0.001-in. aluminum foil and dissolving off the unoxidized surface with HCl. A thin CsI crystal (about 0.012 in.) served to detect the scattered protons. Resonances have been found at 1.65 Mev, total width ≅60 kv, and 2.09 Mev, total width ≅25 kv. In addition, a broad resonance has been found at 2.9 Mev. Superimposed on this broad resonance are two narrow resonances at 3.10 and 3.34 Mev which have previously been reported[1] from a study of the inelastic gamma radiations from $Si^{28}(p,p',\gamma)Si^{28}$. An analysis of the data is now in progress.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Cohn, Blair, Kington, and Willard, Phys. Rev. **99**, 644 (1955); also private communication.

K12. Elastic Scattering of Alpha Particles by Carbon-14.* J. A. WEINMAN AND E. A. SILVERSTEIN, *University of Wisconsin.*—The elastic scattering of alpha particles by C^{14} has been observed for alpha energies between 2 and 3.9 Mev and for $\theta_{c.m.}=169°$, 149.5°, 140.8°, 125.3°, and 90°. The solid targets of 38.6% C^{14} were at least 8 kv thick. Energies of both the incident and scattered particles were measured with cylindrical electrostatic analyzers. Anomalies in the elastic scattering were observed at $E_\alpha^{\text{lab}}=2.34$, 2.56, 2.65, and 3.7 Mev. The off-resonance low-energy cross section is normalized to Rutherford scattering, and dispersion formalism is being used to obtain resonance energies, angular momenta, parity, and reduced widths of the corresponding O^{18} levels. Preliminary results give $J=1^-$ (or 0^+ ?), 2^+, 3^- for the first three resonances. The $E_\alpha=3.7$ Mev anomaly is shown to involve more than one level.

* Work supported by the U. S. Atomic Energy Commission, and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.

K13. Scattering of 18.4-Mev Alpha Particles by Oxygen.* J. C. CORELLI, E. BLEULER, AND D. J. TENDAM, *Purdue University.*—The scattering of 18.4-Mev alpha particles from a gaseous target of spectroscopically pure oxygen was measured in the range of 10° to 170° (laboratory) with the aid of nuclear plates spaced every 2.5°. The elastic distribution exhibits oscillations with deep minima at 46°, 75°, 101°, 114°, 135°, and 159° (c.m.). The cross section is about 1000 mb/sterad at 19°, 0.2 mb/sterad at the 114° minimum, and rises to 300 mb/sterad at 170° (200 times Rutherford cross section). The ratios between successive maxima and minima are as large as 50. No estimate of the interaction radius is possible since the spacing of the minima is not sufficiently regular. The cross section for inelastic scattering, O^{16} being left in the unresolved 6.06- and 6.14-Mev states, was measured up to 115°; it shows irregular fluctuations with only two pronounced minima at 43° and 84° and a rise in the forward direction. It is hoped that preliminary results on the scattering by S^{32} can be presented, and a summary of the elastic scattering of 18- to 19-Mev alpha particles by Ne, Al, A, Cu, and Ag will be given.

* Supported in part by the U. S. Atomic Energy Commission.

K14. Measurement of Anisotropic Neutron Spectra from 50 to 1000 kev with Nuclear Emulsions Containing Specks of Li^6 Glass.* J. H. ROBERTS AND F. E. KINNEY, *Northwestern University.*—Extensive studies have been made of the measurement of anisotropic neutron spectra with Ilford *E*1 nuclear emulsions loaded with a layer of specks of Li^6 glass.[1] Calibrations have been made with rotated plates exposed to monoergic neutron groups. Measurements of known neutron spectra have been made to check the reliability of the technique. Triton-alpha pairs originating in glass specks can be measured in the presence of a high proton background. The method of analyzing the data and the results obtained will be presented.

* Work supported by Argonne National Laboratory.
[1] Roberts, Haugsnes, and Wood, Phys. Rev. **93**, 920 (1954).

THURSDAY MORNING AT 10:00

Empire Suite

(L. J. HAYNER presiding)

General Physics

KA1. Trapping of Helium Ions by Molybdenum Surfaces.* L. J. VARNERIN AND J. H. CARMICHAEL, *Westinghouse Research Laboratories.*—A study has been made of the ionic cleanup or pumping of helium into molybdenum surfaces. It has been established that trapping of ions at the surface constitutes the sole pumping mechanism in this simple case. Curves of trapping efficiency η (atoms removed/ions collected) as a function of ion impact potential have been obtained. A detailed study of the re-emission rates of helium already pumped was made to aid in an understanding of the trapping mechanism. While the physical mechanism is not well understood, the contribution of the re-emission mechanism to the pumping process can now be understood in some detail.

* This research was supported in part by the U. S. Air Force through the Office of Scientific Research, Air Research and Development Command.

KA2. Sputtering of Surfaces by Positive-Ion Beams of Low Energy. RICHARD E. HONIG, *RCA Laboratories.*—Ion beams of noble gases (He, Ne, A, Kr, and Xe; energy: 30–400 ev; intensity: 1–10 $\mu A/cm^2$) have been employed to bombard Ag, Ge, and Ge-Si alloy surfaces. The secondary particles sputtered off, and neutrals as well as positive and negative ions were identified and recorded in a 180° mass spectrometer of 5.5-in. radius. They represented partly background gases adsorbed on the surface, partly atoms and molecules characteristic of the sample. Among the latter particles, neutrals were found to be about 100 times more abundant than those coming off as positive ions. Rather low yields (about one sample atom per 100 incident ions of 400-ev energy) and relatively high thresholds (about 40 ev for an incident angle of 30°) are believed to be due to surface contamination. After bombardment, the

surfaces showed pits similar to those observed by Wehner[1] and to etch pits. Effects of various sputtering parameters on yield and threshold will be discussed and more details given concerning the sputtered particles observed. If the effects of surface contamination can be reduced, this method promises to be useful in the analysis of solid surfaces.

[1] G. K. Wehner, Phys. Rev. **102**, 690 (1956).

KA3. Ion Induced Re-Emission of Noble Gases from the Surface of a Metal Wall Ion Gauge.* E. A. TRENDELENBURG AND J. H. CARMICHAEL, *Westinghouse Research Laboratories.*—It is well known that gases absorbed in metal surfaces can be released by means of an electron[1] or ion[2] impact. Using a mass spectrometer to identify the different masses, as described by Brown and Leck,[3] experiments were performed in which various noble gases were driven into a metal surface via ion bombardment at 100 ev and were released by subsequent ion bombardment with different noble gases. The gases used included helium, neon, argon, and krypton, which were all used both as the absorbed and the bullet gas in all twelve possible combinations. The re-emission rate, dn/dt, for gas M_1, the absorbed gas, being released by gas M_2, the bullet gas, is a function of both M_1 and M_2. The re-emission curves, dn/dt *vs* t, although not single exponentials as expected from a simple picture, may be described in some cases by a summation of two or more exponentials indicating different ion induced re-emission terms.

* This project was supported by the U. S. Atomic Energy Commission.
[1] W. Von Meyeren, Z. Physik **91**, 727 (1934).
[2] H. Schwarz, Z. Physik **122**, 437 (1944).
[3] E. Brown and J. H. Leck, Jr., J. Appl. Phys. **6**, 161 (1955).

KA4. Charge Analysis of Helium, Neon, and Argon Single Collisions at Energies to 100 kev.* E. N. FULS, P. R. JONES, AND E. EVERHART, *University of Connecticut.*—The charge states of scattered helium, neon, and argon ions incident on similar gas targets have been measured at each angle out to forty degrees with a resolution of one degree.[1] Data are presented for $He^+ \rightarrow He$, Ne, A; $Ne^+ \rightarrow Ne$, A; and $A^+ \rightarrow A$ single collisions at energies of 25, 50, and 100 kev. The ion beam traversed a collision chamber containing a target gas whose pressure was maintained low enough to insure single interactions. The scattered particles at each angle passed through a pair of collimating holes and then through an electrostatic analyzer which separated the various charge states. The collision products were detected by a Faraday Cage and a secondary election multiplier and were found to have charge states ranging from zero to seven times ionized depending on the gases and energy involved. Plots of the percentages of the various charge states *vs* angle indicate a functional dependence on both energy and angle.

* This work was sponsored by the Office of Ordnance Research through the Ordnance Materials Research Laboratory at Watertown and the Springfield Ordnance District.
[1] See also Carbon, Fuls, and Everhart, Phys. Rev. **102**, 1524 (1956).

KA5. Phenomenological Theory of Ionization Produced by High-Energy Atomic Collisions.* ARNOLD RUSSEK, *University of Connecticut.*—When two atoms collide at high energies, the scattered systems may become ionized, as discussed in the preceding paper. A phenomenological theory has been developed which accounts for the respective probabilities that the scattered systems will be found in the various states of ionization. The collision ionization is regarded as a two-step process. First, as the two charge distributions sweep through each other, a relatively small amount of energy E_T is transferred from the kinetic energy of translation to the internal degrees of freedom, similar to the frictional transfer of mechanical energy to heat. This energy transferred depends on the relative trajectory pursued and, therefore, on the parameters describing the collision. Second, this "heat" energy evaporates some of the electrons. The statistics of evaporation from small systems has been studied, giving the probabilities of the states of ionization as functions of E_T and, therefore, of the collision parameters. The theory accounts for data obtained for $A+$ on A scattering at 25, 50, and 100 kev.

* Sponsored in part by the Office of Ordnance Research, U. S. Army, through the Watertown Arsenal and the Springfield Ordnance District.

KA6. Use of an Electro-Optical Method to Determine Detonation Temperature in High Explosives.* F. C. GIBSON, M. BOWSER, C. R. SUMMERS, F. SCOTT, AND C. M. MASON, *Bureau of Mines.*—A method has been devised for sampling the radiation from the interior of a detonating solid explosive charge by introducing a transparent methyl methacrylate rod axially into the charge at the time of fabrication. The radiation was analyzed by a grating spectrograph using four bands 100 A wide, 600 A apart. The radiation intensities were used to calculate the color temperatures within the detonating explosive. The apparatus was calibrated by a radio-frequency excited lamp known to have gray-body radiation. The explosive charges were vacuum impregnated with propane to replace the air in the intergranular voids to eliminate light emission from the air shock. The temperatures obtained at two densities were

Substance	1.0 g/cm³	1.6 g/cm³
PETN	5250°K	5750°K
Tetryl	4750°K	5400°K
RDX	5800°K	5600°K
EDNA	5500°K	5250°K

The temperature obtained from detonating nitroglycerin looking end-on through the undetonated explosive without a plastic rod was 4100°K.

* Supported by the Office of the Chief of Ordnance, U. S. Army.

KA7. Static Electrification of Filaments: Effect of Resistivity on Velocity Dependence of Transferred Charge. R. G. CUNNINGHAM AND D. J. MONTGOMERY, *Michigan State University.*—Charge transfer upon rubbing filaments under controlled mechanical and ambient conditions was investigated by Hersh and Montgomery.[1] With their apparatus it was not possible to determine directly whether the charge observed was limited by atmospheric breakdown. A new apparatus has been built for making similar measurements, with a photomultiplier placed near the samples to detect sparking upon breakdown. The majority of the results of Hersh and Montgomery are confirmed. Further results have been obtained for charge dependence on velocity v, at varying resistivity ρ. The resistivity is determined by fixing relative humidity and ambient temperature. As suggested by theory, the charge retained on the filaments of fixed geometry is found to depend to a large extent on the product $\epsilon\rho v$, where ϵ is the dielectric constant.

[1] S. P. Hersh and D. J. Montgomery, Textile Research J. **25**, 279 (1955).

KA8. Some Regularities in Energy Coefficient (EC) Values. N. EFREMOV.—Energy coefficient (a concept introduced by Fersman) is an empirical constant representing contribution of an element to the lattice energy of its compounds. The formula for calculation of EC values for monovalent alkaline ions was given before.[1] On the basis of the EC values for monovalent alkaline ions (Li^{1+}, Na^{1+}, K^{1+}, etc.) the EC values for other ions may be obtained due to a simple regularity. The energy coefficients for ions with increasing valence situated along the diagonal in the Periodic System, such as Li^{1+}, Mg^{2+}, Sc^{3+}, or Na^{1+}, Ca^{2+}, Y^{3+}, are related as squares of their valences ($1^2:2^2:3^2$ or $1:4:9$). These EC values are in good agreement with Fersman's[2] empirical data, e.g.:

Ions	Li^{1+}	Mg^{2+}	Sc^{3+}
Calculated EC's	0.55	2.20	4.95
Empirical EC's	0.55	2.15	4.65

[1] N. Efremov, Bull. Am. Phys. Soc. Ser. II, **1** (1956).
[2] A. E. Fersman, Geochem. (U.S.S.R.) **III**, 92 (1937).

KA9. Gyratron—A New Solid State Quantum-Mechanical Amplifier.* M. W. P. STRANDBERG, *M. I. T.*—Of the several methods of realizing a coherent electromagnetic amplifier using quantum-mechanical energy levels, there is one we choose to call the Gyratron, or "electron spin tool." Some of the possible operating characteristics of such a device will be described. The use of a Gyratron as a thermal amplifier, or as a radio telescope preamplifier, or as a radar or scatter communications preamplifier will be discussed.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

THURSDAY AFTERNOON AT 2:00

Manhattan Center

(H. D. SMYTH presiding)

Joint Ceremonial Session of APS and AAPT

Retiring Presidential Address of the American Physical Society

L1. Relativistic Concepts and Quantum Phenomena. E. P. WIGNER, *Princeton University.*

(W. C. MICHELS presiding)

Presentation of the Oersted Medal of the AAPT

Response of the Oersted Medallist

L2. Fashions in Thermodynamics. MARK ZEMANSKY, *College of the City of New York.*

Fifteenth Richtmyer Memorial Lecture of the AAPT

L3. Antinucleons. EMILIO SEGRÈ, *University of California, Berkeley.*

FRIDAY MORNING AT 9:30

Terrace Room

(W. A. NIERENBERG presiding)

Magnetic Resonance, II; Positronium

M1. Paramagnetic Resonance Detection along the Polarizing Field Direction. G. WHITFIELD AND A. R. REDFIELD, *IBM Watson Laboratory.*—Several writers[1] have suggested modifying the Bloch equations so that the magnetization will tend to relax toward the instantaneous applied magnetic field rather than the fixed field. For the case where a fixed field (H_s) and a perpendicular circularly polarized rf field (H_1) are applied to a sample, both the modified and unmodified Bloch equations have exact steady state solutions which differ from each other appreciably when H_s is smaller than H_1 or the line width in gauss. In the case where $H_s=0$, the modified equations give a finite dc magnetization in the z direction (M_s) and the unmodified equations give $M_s=0$. The z component of the electronic spin magnetization of diphenyl pycril hydrazil was measured, with H_s ranging from $+20$ to -20 gauss and with a circularly polarized rf up to 6 gauss at 19.5 mc. The dc magnetization was observed by turning the rf on and off at 280 cps and picking up the resultant changes in magnetization with a 30-thousand turn coil oriented along the z axis. The measurements agree with the predictions of the modified Bloch equations. In particular, a clear indication of the existence of a z component of magnetization was obtained when $H_s=0$.

[1] Codington, Olds, and Torrey, Phys. Rev. **95**, 607 (1954); M. A. Garstens and J. I. Kaplan, Phys. Rev. **99**, 459 (1955).

M2. Paramagnetic Resonance Spectrum of Gd^{3+} in CaF_2.†* W. LOW, *University of Chicago.*—Paramagnetic resonance spectrum has been observed at room and liquid helium temperatures on single crystals of CaF_2 containing less than 0.05% of Gd. The spectrum consists of seven lines, three on each side of the $\frac{1}{2}\rightarrow-\frac{1}{2}$ transition at the approximate distances of 10:6:5. The spectrum is characteristic of a cubic field and indicates that any vacancy or interstitial F^- ion must be far removed from the trivalent ion. The spectrum can be fitted with $g=1.991\pm0.002$ and $\delta=+0.0175$ cm^{-1}, where 8δ is the total splitting of the $^8S_{7/2}$ ground state of gadolinium in a cubic field. The positive sign of δ was determined from relative intensity measurements of the fine structure lines at liquid helium temperature. The difference in the spectra reported by Bleaney *et al.*[1] on Nd^{3+} in CaF_2 and ours may possibly depend on the way the crystal was prepared and on the concentration of the trivalent impurities.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Bleaney, Llewellyn, and Jones, Proc. Phys. Soc. (London) **B69**, 858 (1956).

M3. Hyperfine Structure and Line Width in *F*-Center Spin Resonance.* G. J. WOLGA AND M. W. P. STRANDBERG, *M. I. T.*—The paramagnetic resonance spectrum of *F* centers

in alkali halide single crystals is being investigated at room and low temperatures. Hyperfine structure has been resolved completely in LiF and NaF and partially in NaCl. The observed line widths are interpreted as arising from interaction with surrounding nuclei of the alkali halide lattice. The spacing of the hyperfine lines is interpreted on the basis I·S type of interaction.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

M4. Spin Relaxation Spectroscopy with Water. S. BROERSMA, *Northwestern University.*—The existence of a water atmosphere around para or diamagnetic ions in solution causes the rate of relaxation to vary locally while at the same time it prevents a rapid averaging. The customary ac modulation of the magnetic field produces the transient conditions which enable the observation of two relaxation phases. These water molecules, or protons, for which the average time of adsorption is close to the local relaxation time, prevail in the observation. The transient rate of relaxation of the entire sample is approximately equal to this rate of adsorption and to the sweep frequency at which the magnetizations of the phases balance. The lifetime found for the inner layer of water surrounding trivalent ions, by studying diamagnetic solutions, is ten milliseconds. For dilute paramagnetic solutions the values range from three hundred to one microsecond, decreasing with increasing distance to the ion. The water atmosphere changes from one or two layers for dilute to two or three layers for concentrated solutions. Ice crystals with four layers' radius and three milliseconds' lifetime show up. The phases are distinguished on the basis of their relaxation history. The signal of the weak relaxation phase can be diminished by inducing eddy currents in the magnet iron, de-uniformizing the field.

M5. Production of Triplet *P* States of Helium in a Beam.* J. A. WHITE, V. W. HUGHES, C. DRAKE, AND A. LURIO, *Yale University.*—The $M=+1$ magnetic substate of a refocused beam of metastable $^3S_1$ He atoms was selected by use of a wire stop in an atomic beam magnetic resonance apparatus.[1] Unpolarized light from a low voltage, 60-w helium arc lamp (Osram spectral lamp) caused a defocusing of about 10% of the refocused beam, which corresponds to a detected signal of 2×10^{-14} amp. The defocusing (light flop) is interpreted as due to a change in M value which can be associated with the process of excitation of a $^3S_1$ atom to a ^3P state and its subsequent decay back to the $^3S_1$ state. The use of optical filters indicated that the excitation is primarily to the $1s\,2p$, ^3P states, which occurs at a wavelength of 10 830 A. The amount of defocusing agrees in order of magnitude with the theoretical estimate. The production of the $n=2$, ^3P states of He in a beam should allow a high precision measurement of the fine structure separations of these states by a combined optical-microwave atomic beam magnetic resonance method.[2]

* This research has been partially supported by the National Science Foundation and by the Air Force OSRD.
[1] Hughes, Tucker, Rhoderick, and Weinreich, Phys. Rev. **91**, 828 (1953).
[2] Perl, Rabi, and Senitsky, Phys. Rev. **98**, 611 (1955).

M6. Zeeman Effect of Neon and Argon in Metastable $^3P_2$ State.* C. DRAKE, V. W. HUGHES, AND A. LURIO, *Yale University.*—The electronic g_J values of neon and argon in their metastable $^3P_2$ state have been measured by the atomic beam magnetic resonance method.[1] The metastable atoms were produced in a glow discharge and detected by electron ejection from a wire. The magnetic field of about 550 gauss was calibrated by use of a Zeeman transition in the metastable $^3S_1$ state of helium.[2] The theoretical g values were calculated to the experimental precision taking into account quantum electrodynamic and relativistic contributions and state perturbations.[3] The experimental and theoretical results agree and are

	g_J (exptl.)	g_J (theoret.)
Ne	1.5009 ±0.0001	1.5009 ±0.0001
A	1.5009 ±0.0001	1.5010 ±0.0001

The Zeeman transition in the metastable $^3P_2$ state of krypton was observed with an intensity considerably less than that for Ne and A.

* This research has been partially supported by the Air Force OSRD.
[1] Weinreich, Tucker, and Hughes, Phys. Rev. **87**, 290(A) (1952).
[2] Hughes, Tucker, Rhoderick, and Weinreich, Phys. Rev. **91**, 828 (1953).
[3] W. Perl and V. W. Hughes, Phys. Rev. **91**, 842 (1953); Abragam and Van Vleck, Phys. Rev. **92**, 1448 (1953); W. Perl, Phys. Rev. **91**, 852 (1953).

M7. Delayed Coincidence Analyzer for Short Lifetime Measurements. A. W. SUNYAR, *Brookhaven National Laboratory.**—A simple modification of the usual pulse limiter-diode mixer coincidence system has been placed in operation. The charge passed by the coincidence diode during overlap of the shaped, limited signals is made approximately proportional to overlap time. This charge is integrated and time information is obtained by analysis of the resulting coincidence output pulse amplitude distribution. The new method results in a considerable reduction in the time for collection of data. Analysis of the data for time information will be discussed. Measurements have been made on the mean life of positrons in Pb. We find $\tau_{Pb}=(1.6\pm0.15)\times10^{-10}$ sec, in agreement with some previous determinations,[1] but in disagreement with a recent determination.[2] Mean lives have been determined for the following nuclear gamma rays: Pb^{207}(570 kev), $(1.1\pm0.15)\times10^{-10}$ sec; Hg^{198}(411 kev), $(2.6\pm1.5)\times10^{-11}$ sec; Xe^{131}(364 kev), $\sim3\times10^{-11}$ sec, and Te^{125}(564 kev), $\leq2\times10^{-11}$ sec. The measured mean lives of the states in Pb^{207} and Hg^{198} are in agreement with the determinations of other workers.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] R. E. Bell and R. L. Graham, Phys. Rev. **90**, 644 (1953).
[2] T. R. Gerholm, Arkiv Fysik **10**, 523 (1956).

M8. New Type of Apparatus for Measurement of the Angular Correlation of Annihilation Radiation.* RODOLFO CASTILLO-BAHENA† AND WALTER E. MILLETT, *University of Texas.*—The apparatus described in previous investigations of this type[1] makes use of two rectangular collimators. The angular acceptance in one plane is made narrow but that in the other plane is broad. The new type of apparatus makes use of a circular slit in one collimator and a circular hole in the other. The advantages obtained by this arrangement may be understood by considering the following fact. If one of two annihilation gamma rays correlated at an angle θ passes along a line, then its partner must pass along a cone of angle θ which is symmetric about the line of the first. The new arrangement therefore has an increased solid angle without deterioration of the resolution. In fact, both the solid angle and the resolution are increased by going from rectangular slits to circular slits. The method of determining the resolution curves of the apparatus and of correcting the data according to these resolution curves will be discussed.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command.
† Recipient of an E. D. Farmer Scholarship and a special study grant from the Instituto Tecnologico de Monterrey.
[1] De Benedetti *et al.*, Phys. Rev. **77**, 205 (1950); Lang *et al.*, Phys. Rev. **99**, 596 (1955); A. T. Stewart, Phys. Rev. **99**, 594 (1955); Page *et al.*, Phys. Rev. **98**, 206 (1955).

M9. Angular Correlation of Annihilation Radiation in Alkali Halide Crystals.* WALTER E. MILLETT AND RODOLFO CASTILLO-BAHENA,† *University of Texas.*—The apparatus described in the preceding paper has been used to measure the angular correlation of the two photon annihilation gamma rays produced when positrons annihilate in single crystals of LiF, NaCl, KCl, KBr, and KI. There are definite well-resolved

peaks in the momentum distribution obtained from the analysis of this data. The position of these peaks is accounted for quantitatively in terms of the following model. The positron is thermalized and then becomes bound to the halogen ion in the crystal. The annihilation then takes place with either (1) an electron belonging to the system to which the positron is bound or (2) an electron from outside the system. The resultant momentum of the two photons depends in the first case upon the binding energy of the positron to the halogen ion, the binding of the electron to the neutral halogen, and the excitation or ionization energy of the recoil neutral halogen. In case (2) the momentum resultant depends essentially only upon the binding energy of the positron to the halogen ion.

* This research was supported by the U. S. Air Force through the Air Force Office of Scientific Research of the Air Research and Development Command under Contract.
† Recipient of an E. D. Farmer Scholarship and a special study grant from the Instituto Tecnologico de Monterrey.

M10. Redetermination of Hyperfine Structure of Positronium.* S. MARDER AND C. S. WU, *Columbia University*, AND V. W. HUGHES, *Yale University and Columbia University*.—The energy difference $\Delta\nu$ between *ortho*positronium and *para*positronium in the ground $n=1$ state has been redetermined in an experiment similar to that of Deutsch, Brown, and Weinstein.[1] The present experiment was done at a magnetic field H of about 8000 gauss which corresponds to a transition frequency of 2460 Mc/sec. A fractional line width $(\Delta H/H)$ of 4.5×10^{-3} was obtained. The principal part of the line width (3.1×10^{-3}) is due to the annihilation lifetime of positronium; microwave power broadening and magnetic field inhomogeneity account for the remainder. No Doppler broadening is expected despite the high velocity of positronium atoms, because the mean free path of a positronium atom in the gas is small compared to the wavelength of the microwave radiation.[2] The result is $\Delta\nu=(2.0333\pm0.0004)\times10^5$ Mc/sec, in which the error is due mainly to inhomogeneity of the magnetic field. This value agrees with the values of Deutsch *et al.* of $(2.0338\pm0.0004)\times10^5$ Mc/sec and $(2.0335\pm0.0005)\times10^5$ Mc/sec done at fields of 9500 and 9000 gauss, respectively. The experimental values confirm the theoretical value of 2.0337×10^5 Mc/sec, computed to order α^3Ry.[3]

* This research has been partially supported by the U. S. Atomic Energy Commission.
[1] Deutsch, Brown, and Weinstein, Phys. Rev. **85**, 1047 (1952); **94**, 758(A) (1954); **98**, 223(A) (1955).
[2] J. P. Wittke and R. H. Dicke, Phys. Rev. **103**, 620 (1956).
[3] R. Karplus and A. Klein, Phys. Rev. **87**, 848 (1952).

M11. Long Positron Lifetime in Liquid Helium. D. A. L. PAUL AND R. L. GRAHAM, *Chalk River Laboratories*.—A more detailed study of positron annihilation in liquid helium has revealed the presence of a longer lived component in addition to the two shorter components reported previously.[1] A long-lived component has also been detected recently by other workers.[2] The mean life is found to be $(9.1\pm0.5)\times10^{-9}$ sec at 4.2°K and atmospheric pressure and the intensity is estimated to be ~13%. The annihilation pulse height spectrum taken in delayed coincidence has been compared with those of positrons in freon 12 and in metals. A comparison of spectrum shapes shows that nearly 60% of the long-lived component in liquid helium decays by three-quantum emission. We conclude that the long-lived component is due to triplet positronium having essentially free state properties since both the lifetime and the spectrum shape analysis indicate similar amounts of quenching. Experiments in liquid and solid helium under various conditions (temperature 1.4 to 4.2°K and pressures up to 68 atmos) show that the long lifetime (a) is not influenced noticeably by the superfluid state and (b) decreases in general with increasing helium density.

[1] Graham, Paul, and Henshaw, Bull. Am. Phys. Soc. Ser. II, 1, 68 (1956).
[2] J. D. Wackerle and R. Stump, Bull. Am. Phys. Soc. Ser. II, 1, 351 (1956).

M12. Free-Positron Annihilation in Liquid Helium. R. L. GRAHAM AND D. A. L. PAUL, *Chalk River Laboratories*.—The most intense positron lifetime component in liquid helium has been re-examined in the light of the information presented in the preceding abstract. After correcting for the presence of the long-lived component we now find the mean life to be $(1.83\pm0.15)\times10^{-9}$ sec at 4.2°K and one atmosphere pressure. This is shorter than the uncorrected value reported previously.[1] Using four NaI(Tl) scintillation counters and a Na^{22} source the three quantum annihilation rates in coincidence with 1.28-Mev photopeak pulses have been measured at various time delays and for various absorbers. From these experiments we determine that the part of the three-quantum rate associated with the 1.8×10^{-9} sec component in liquid helium is, within errors, the same as that in metals and is much less than that to be expected if this component were due to some form of triplet positronium. Experiments at temperatures down to 1.5°K under saturated vapor pressure suggest (a) no detectable change in mean life near the λ point and (b) a decrease in lifetime with increasing density. This lifetime component appears to be due to the annihilation of free positrons.

[1] Graham, Paul, and Henshaw, Bull. Am. Phys. Soc. Ser. II, 1, 68 (1956).

FRIDAY MORNING AT 10:00

Panel Room

(J. A. WHEELER presiding)

Theoretical Physics, III: Strangle Particles, Other Topics

MA1. Mass Differences of Baryon Isotopic Multiplets.* E. C. G. SUDARSHAN AND R. E. MARSHAK, *University of Rochester*.—The mass differences among the components of the various baryon isotopic multiplets, interpreted as electromagnetic in origin, enable one to infer certain parameters concerning the anomalous magnetic moments of the baryons. It is postulated that the anomalous moments arise from the strong coupling of the baryons to the pion and K-meson fields. We have shown[1] that the larger mass of the Σ^- relative to Σ^+ is inconsistent with a pseudoscalar coupling of the $N\Sigma K$ (and $\Xi\Sigma K$) fields, while scalar coupling predicts a mass difference of the correct sign. For scalar coupling, the dominant contribution to the anomalous moment comes from the Dirac moment of the baryon in the intermediate state, if one neglects the effect of very high frequency virtual K mesons. Calculations for the neutral Σ show that its anomalous moment and mass lie between the values of the corresponding quantities for Σ^+ and Σ^-. Scalar coupling of the Ξ field to K mesons leads to a negative anomalous moment for Ξ^- and no moment for Ξ^0; the coupling to the pion field leads to approximately equal and opposite moments. Scalar coupling of the nucleon to K-mesons leads to an almost equal enhancement of the pion contribu-

tions to the anomalous moments of N^0 and N^+. The effects on the mass differences among the components of the Ξ and N baryons will be presented.

* This work has been supported in part by the U. S. Atomic Energy Commission.
[1] E. C. G. Sudarshan and R. E. Marshak, Phys. Rev. **104**, 267 (1956).

MA2. Λ-Nucleon Force with $S\Sigma=\frac{3}{2}$.* M. T. VAUGHN AND D. C. PEASLEE, *Purdue University*.—Pion exchange $\Lambda-N$ forces are estimated in accordance with the possibility that the spin of the intermediate Σ state may be $\frac{3}{2}$.[1] The Λ is taken to have $S=\frac{1}{2}$ and the same parity as the Σ, and a phenomenological interaction operator $(S\cdot\nabla)$ assumed with matrix elements proportional to Clebsch-Gordan coefficients for vector addition $\frac{1}{2}+1=\frac{3}{2}$. The term corresponding to V_3 in ordinary nuclear forces does not operate directly but only through mixing in Σ states. Its effect is therefore dependent on the structure of the nuclear core in a hyperfragment, but this structure dependence appears negligible in the present case. The $\Lambda-N$ potential $(V_3)^2+V_4$ in the region $\mu r\sim 1$ is attractive but only quite weakly spin-dependent.

* Assisted by Air Force Office of Scientific Research.
[1] Seattle Conference (September, 1956).

MA3. Photoproduction of K Mesons.* MASAAKI KAWAGUCHI, *Purdue University*.—The processes $\gamma+p\rightarrow K^++\Lambda^0$ and $\gamma+p\rightarrow K^0+\Sigma^+$ are investigated in terms of the lowest order perturbation calculation, on the assumption that the nucleon-hyperon pair coupling is relatively weak. The $K+\Lambda$ cross sections are obtained straightforwardly by simple modifications of the results of photo-pion production. For example, (i) with $\Lambda=\frac{1}{2}^+$ and $K=0^+$, or $\Lambda=\frac{1}{2}^-$ and $K=0^-$, the result of $s(s)$ meson theory is available, and (ii) $ps(ps)$ theory for $\Lambda=\frac{1}{2}^+$ and $K=0^-$, or $\Lambda=\frac{1}{2}^-$ and $K=0^+$. The former shows a peak at forward laboratory angles and the latter does not. Therefore, if experiment could distinguish between a single one of these angular distributions and a superposition of the two, it would in principle be possible to decide whether or not the Λ, K are parity doublets. For production of $K+\Sigma$ the treatment is more complicated if the Σ spin is taken as $\frac{3}{2}$.

* Supported by the Air Force Office of Scientific Research.

MA4. Hyperon-Nucleon Interaction and Hyperon-Exchange Scattering.* D. B. LICHTENBERG AND MARC ROSS, *Indiana University*.—Using a previously described model[1] for the interaction between pions and hyperons, a 2 by 2 matrix potential has been calculated which describes the forces between hyperons and nucleons. The diagonal elements are Λ-nucleon and Σ-nucleon potentials while the off diagonal elements describe the hyperon-exchange processes $\Sigma+\mathfrak{N}\rightleftarrows\Lambda+\mathfrak{N}$. The use of this matrix potential in the Schrodinger equation leads to two coupled differential equations (or four in the case of tensor forces) whose solutions yield the low-energy hyperon-nucleon elastic and inelastic scattering cross sections. It is observed experimentally that the binding energy of the Λ in hyperfragments increases approximately linearly with the atomic number A of the fragment in the range $A=3$ to $A=8$. The data can be fitted with phenomenological Λ-nucleus potentials. Under certain simplifying assumptions, it is possible to relate these potentials to a spin-dependent Λ-nucleon potential. This phenomenological Λ-nucleon potential is then compared with the low-energy scattering solutions of our model. The ratio for Λ to Σ production in nuclei predicted by these solutions will also be discussed.

* Work supported by the National Science Foundation.
[1] D. B. Lichtenberg and Marc Ross, Phys. Rev. **103**, 1131 (1956).

MA5. Scattering of K^+ Mesons by Protons. B. H. MCCORMICK* AND R. M. STERNHEIMER,* *Brookhaven National Laboratory*, AND ABRAHAM KLEIN,† *University of Pennsylvania*.—The scattering of positive K mesons by hydrogen has been investigated under the dual hypotheses that (i) the K meson has spin zero, and that (ii) the K meson can emit and absorb pions singly. In the field theoretic analysis, the potential acting between a K particle and a nucleon has been calculated, including those contributions arising from the exchange of at most two pions. Turning then to the phenomenological analysis, without making a definite commitment as to the specific form of the K-P potential, we have separated the Schrodinger equation into partial waves. The eigenphases and mixing parameters which asymptotically define the solutions of this coupled equation are then related to the scattering amplitude, the differential and total cross section. Guided by the field-theoretic potential, a variety of phenomenological potentials have been tested. A fit to the preliminary data seemingly requires destructive interference between those contributions to the scattering from virtual hyperon formation and that contribution from the Schwinger pion exchange mechanism, specifically, a repulsive core radius $r_c\leq 10^{-14}$ cm and $g_{\pi\Lambda}^2/4\pi<0.2$, are at present indicated.

* Work done under the auspices of the U. S. Atomic Energy Commission.
† Supported in part by the Air Force Research and Development Command.

MA6. Hyperfragment Binding with Parity Mixing.* LAURIE M. BROWN, *Northwestern University*.—The suggestion that there may exist two Λ^0-particles of opposite parity and the possible existence of strong interactions which can change the intrinsic parity lead to consideration of a phenomenological potential for hypernuclear binding of the form $V_1(r)+(\boldsymbol{\sigma}\cdot\mathbf{r})C_PV_2(r)$, where $\mathbf{r}$ is the position vector of the Λ^0 with respect to the center of mass of the nuclear "core," $\boldsymbol{\sigma}$ is the spin vector of the (spin $\frac{1}{2}$) Λ^0, C_P is the operator introduced by Lee and Yang which changes the intrinsic parity of the Λ^0, and $V_1(r)$, $V_2(r)$ are central scalar potentials. The lowest bound state of this potential is a mixture of S and P states. Assuming the $\Lambda-N$ force to be of relatively short range, V_1 and V_2 are taken as square wells having the radius of the nuclear "core," and a variation-iteration procedure is used to determine the well depths and the percent of P-state for given $c=V_1/V_2$. The mixing is appreciable, e.g., for 6-Mev binding energy ($_\Lambda$Be^9) the percentages of P state are about 21, 13, 9, 5 for $c=0$, $\frac{1}{4}$, 1, 2, respectively.

* Supported in part by the U. S. Atomic Energy Commission.

MA7. $\pi^+\rightarrow\pi^0+e^++\nu+8$ mc^2. E. FEENBERG AND H. PRIMAKOFF,* *Washington University*.—The possible existence of this decay process is suggested by the observation of events interpreted as $K^+\rightarrow\pi^0+\mu^++\nu$ and $K^+\rightarrow\pi^0+e^++\nu$. The occurrence of $K^+\rightarrow\mu^++\nu$ and $\pi^+\rightarrow\mu^++\nu$ and the absence of $K^+\rightarrow e^++\nu$ and $\pi^+\rightarrow e^++\nu$ reinforces the suggestion. Simple phase space calculations indicate 10^{-6}/pion for the expected yield. Various theoretical connections between this and other K^+ and π^+ decay process will also be discussed. The $\pi^+\rightarrow\pi^0+e^++\nu$ reaction can be detected, against an overwhelming background of normal $\pi^+\rightarrow\mu^++\nu$ decays, by coincidence observation of four photons occurring in oppositely directed pairs with energy m_ec^2 per photon for the pair from the subsequent e^+ annihilation and 132 m_ec^2 per photon for the pair from the decay of the π^0.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

MA8. Level Shift of Mesic Atoms. L. WOLFENSTEIN, *Carnegie Institute of Technology*.—The sign and order-of-magnitude of the level shift of the ground state of π-mesic atoms has been calculated[1] from the meson interaction with individual nuclear nucleons at rest. Brueckner[2] has considered the correction to this calculation due to nucleon motion by treating the virtual meson absorption by a method equivalent to second-order perturbation theory with a recoil term. Instead we have related the effect of the nucleon motion to the meson-

nucleon p-wave scattering by use of an effective meson-nucleon (velocity-dependent) potential and the Born approximation. This method has the advantage of taking into account the great deviations of meson scattering from second-order perturbation theory but the disadvantage of ignoring the enhancement of the virtual absorption due to small energy denominators. The main contribution to our result comes from interactions in the 33 state whereas the virtual absorption occurs only for the 11 state. As a consequence, our result for this effect has the opposite sign from Brueckner's although it has about the same magnitude. We believe the correct result lies between the two.

[1] Deser, Goldberger, Bauman, and Thirring, Phys. Rev. **95**, 774 (1954).
[2] K. A. Brueckner, Phys. Rev. **98**, 769 (1955).

MA9. Vacuum Polarization and the π^0 Decay. T. A. WELTON, *Oak Ridge National Laboratory*.—The calculation of decay rates for many of the short-lived particles is complicated not only by uncertainty as to the fundamental interactions, but also by theoretical ambiguities which are closely related to the elementary vacuum polarization problem. In view of the strong suspicion that the vacuum polarization difficulty is a valid mathematical consequence of an incorrectly formulated theory, a reformulation has been studied which eliminates the obvious difficulties of the vacuum polarization, without recourse to renormalization or convergence factors. The decay of the neutral π meson into two photons presents an interesting contradiction, according to conventional theory. A definite lifetime is predicted which is much shorter than the observed figure. Because pseudoscalar and pseudovector couplings give the same result, appeal to pair suppression seems unreasonable. The reformulation to be discussed gives an identically vanishing result for the triangle diagram, and it can then be hoped that agreement with experiment can be obtained from more complicated graphs. Similar improvements appear in other problems. The square diagram in meson theory now gives a finite, unambiguous contribution, as do the graphs for particle decay by creation of a virtual nucleon pair, with subsequent annihilation.

MA10. Radiative Corrections to Positron Annihilation. ISADORE HARRIS AND LAURIE M. BROWN, *Northwestern University*.—The e^6 corrections to the two-photon direct annihilation of the electron-positron system are calculated by applying the substitution law to the Compton scattering radiative corrections.[1] As the corrected plane wave matrix element diverges for small velocity, owing to failure of the Born approximation, a more accurate treatment of Coulomb effects based on the Sommerfeld factor is used. The infrared divergence is treated in the usual manner, namely by the addition of the low-frequency part of the three quantum annihilation cross section. Since the results[1] of BF are expressed as the real part of a transcendental function which becomes complex for annihilation, a new separation of the real part is performed. Numerical results, together with high- and lowe-nergy approximations, are obtained. The cross sections are reduced by about 4% at 10 Mev (lab) and 0.59% at zero energy. The latter result, applied to the positronium singlet ground state, yields a lifetime increase of the same magnitude. It is shown that the usual treatment of the positronium lifetime is of sufficient accuracy for the e^6 corrections.

[1] L. M. Brown and R. P. Feynman, Phys. Rev. **85**, 231 (1952).

FRIDAY MORNING AT 9:30

Grand Ballroom

(E. A. COOMES presiding)

Symposium of the Division of Electron Physics

N1. Mechanisms of Operation of the *L* Cathode. E. S. RITTNER, *Philips Laboratories*. (30 min.)
N2. Solid-State Masers. N. BLOEMBERGEN, *Harvard University*. (30 min.)
N3. The Excitation of Plasma Oscillations. W. P. ALLIS, *M. I. T.* (30 min.)

Business Meeting of the Division of Electron Physics

(To be held during the session whenever the Chairman chooses.)

FRIDAY MORNING AT 11:45

Grand Ballroom

(L. APKER presiding)

Oliver E. Buckley Lecture

N4. Role of Magnetic-Resonance Studies in the Physics of Solids. CHARLES KITTEL, *University of California, Berkeley*. (40 min.)

FRIDAY MORNING AT 9:30

Boston-Washington Room

(D. J. HUGHES presiding)

Low-Energy Neutron Physics

NA1. Gamma-Ray Transitions in Erbium Excited by Resonant Neutron Capture.* C. A. FENSTERMACHER,† R. L. HICKOK,‡ AND H. L. SCHULTZ, *Yale University.*—The low-energy gamma-ray spectra resulting from resonance-energy neutron capture in erbium§ have been examined for the resonances at 0.46, 0.58, 6.1, and 9.5 ev. The Yale linear electron accelerator was used as a source of photoneutrons and time-of-flight techniques employed. Pulse-height analyses were obtained with a 2½ in. NaI(Tl) scintillation crystal and two multichannel pulse-height analyzers operating simultaneously. Gamma rays of energy 188±10, 280±10, 730±20, and 820±20 kev were observed. The 188-kev gamma ray was the most intense in number of photons per 100 neutron captures (~50) and appeared with equal intensity in all four resonances within an experimental error of 25%. The 280-kev transition was observed in the 0.46- and 0.58-ev resonances with approximately equal intensities (~5). Neutron intensity limitations make difficult the detection of such a weak transition from capture in the 6.1- and 9.5-ev resonances. The investigation is being continued to establish conclusive results regarding the 280-kev transition for these cases. The 730- and 820-kev gamma rays appear after capture in the 0.58-ev resonance which is the only resonance examined to date for these transitions.

* Research supported by the U. S. Atomic Energy Commission.
† duPont Predoctoral Fellow.
‡ Socony Mobile Postdoctoral Fellow.
§ The authors are indebted to Dr. F. H. Spedding, Ames Laboratory, Iowa State College, for making available the erbium sample.

NA2. Rotational Levels in Hf^{178} Excited by Resonance Neutron Capture.* C. K. BOCKELMAN, C. A. FENSTERMACHER,† AND JAMES E. DRAPER, *Yale University.*—Using the experimental method described in the preceding abstract, low-energy, gamma-ray transitions have been observed in Hf^{178} excited by resonant neutron capture at the 1.10- and 2.39-ev resonances in Hf^{177}. For both resonances a capture gamma ray of 90±5 kev was observed in addition to the previously measured 220±10 kev and 330±10 kev radiations.[1] Coulomb excitation experiments[2] suggest that the 90-kev gamma ray originates in a transition from a 2^+ first excited state to the ground state of Hf^{178}. The energies of the 220-kev and 330-kev radiations agree with the energies of transitions from a 4^+ to a 2^+ level and from a 6^+ to a 4^+ level predicted by the simple rotational sequence of the unified model. Measurement of the intensities of these gamma rays at the two resonances are in progress.

* Research supported by the U. S. Atomic Energy Commission.
† duPont Predoctoral Fellow.
[1] Walters, Fenstermacher, Rosler, Bennett, Bockelman, Schultz, and Wadey, Bull. Am. Phys. Soc. Ser. II, 1, 296 (1956).
[2] N. P. Heydenburg and G. M. Temmer, Phys. Rev. 100, 150 (1955).

NA3. Electrostatic Storage System for a 2000-Channel Time-of-Flight Analyzer.* W. W. HAVENS, JR., AND J. HAHN, *Columbia University.*—An instrument has been developed for measuring the time of flight of neutrons which has 2000 discrete time channels, each having a minimum width of 0.1 μsec. Neutrons produced by a cyclotron burst, which occurs at 60 cps, are detected after traversing a fixed flight path. The time of arrival of a neutron is stored at a particular position on the face of a cathode-ray tube. A starting pulse gates a 10 Mc oscillator which feeds pulses to a current adder system that increases the horizontal deflection voltage by 3 volt steps every 0.1 μsec. The vertical deflection voltage is increased by 6 volt steps every 6.4 μsec. Thus a raster of 2048 spots would be formed on the face of the cathode-ray tube if the electron beam were intensified. When a neutron arrives at the detector, the 10 Mc input to the deflection voltage is interrupted and the voltages remain constant for 0.8 μsec. During this 0.8 μsec the electron beam is intensified to place a charge at a particular spot on the cathode-ray tube. After the pulse is thus stored, the deflection voltage advances in one step the number of positions equal to the elapsed time. During the next sweep the deflection voltages are controlled by the magnetic drum system, described below. The information is removed from the cathode-ray tube and transferred to the magnetic drum system before the next burst of neutrons occurs.

* This work was partially supported by the U. S. Atomic Energy Commission.

NA4. Magnetic Drum Storage System for Two-Thousand Channel Time Analyzer. M. L. YEATER AND E. R. GAERTTNER, *Knolls Atomic Power Laboratory,** AND J. STRAND, H. L. GARNER, R. GRAHAM, AND S. MACMILLAN, *Strand Engineering Company.*—The magnetic drum section of the Columbia-KAPL-Yale time analyzer is designed to accumulate neutron detector pulse information from the electrostatic storage system (see preceding abstract). The drum has a storage capacity of 8192 counts in each of 2000 channels; extra tracks on the drum allow for expansion to 4000 channels. It has permanently marked clock tracks which define channel positions and provide synchronizing pulses for the electron beam used to read the electrostatic storage tube. Each of thirteen storage tracks is divided into 2000 channel elements. During operation, stored counts flow during each drum revolution from the storage tracks to arithmetic elements for addition of new counts; each channel count is then returned to its channel via a temporary storage track which holds the information while the channel position rotates from the read to the write heads. Arithmetic and control elements embody circuits similar to those in SEAC and MIDAC digital computers. Etched board wiring is used throughout, providing compact circuit assemblies of maximum reliability. An output oscilloscope monitor is provided which permits a continual review of the accumulated count during an experiment. The contents of the drum are read out to IBM cards or paper tape.

* Operated for the U. S. Atomic Energy Commission by the General Electric Company.

NA5. High-Resolution Studies of Slow Neutron Resonances in U^{238}.* J. ROSEN, J. S. DESJARDINS, W. W. HAVENS, JR., AND J. RAINWATER, *Columbia University.*—The resonances of U^{238} have been studied with the Nevis Neutron Velocity Spectrometer using a source detector distance of 35.21 m, a source on-time about 0.1 μsec, and detector gate widths of 0.25 and 0.50 μsec. Measurements are made using plastic scintillators to detect the capture gamma rays emitted by different thicknesses of foils of the element being studied. Sharp resonance peaks are observed above a smooth background. The areas under these curves are normalized at each resonance by determining the maximum counting rate obtained with a thick sample. Transmission measurements are also made using identical foils at the detector and at the transmission position. The measurements have been carried out up to 700 ev. Above 300 ev several resonances previously reported

as single have been resolved into more than one resonance. In the energy interval studied, the number of resonances per 100-v interval varies from 6 in the region from 0 to 100 v to 2 in the region from 300 to 400 v, with the average level spacing remaining apparently constant over the whole interval. Methods and results of analyses will be presented.

* This work was partially supported by the U. S. Atomic Energy Commission.

NA6. Results on High Resolution Studies of the Neutron Resonances in Ta, Ag, and Cd.* J. S. DESJARDINS, J. ROSEN, J. RAINWATER, AND W. W. HAVENS, JR., *Columbia University.*—The accuracy of the results obtained in the studies of the slow neutron resonances of silver and tantalum have been improved substantially by increasing the statistical accuracy of the data. Resonance levels which were previously lost in the background are now clearly distinguishable. Measurements on silver have been extended up to 600 ev. Measurements on tantalum have not been extended beyond 275 ev because of the small level spacing. Results of analysis of resonance levels in Ta and Ag will be presented. Preliminary results have been obtained on the neutron resonance levels of Cd, and analysis of these levels is in progress.

* This work was partially supported by the U. S. Atomic Energy Commission.

NA7. Neutron Resonance Parameters for Sm^{147}, Sm^{149}, Gd^{155}, and Gd^{157}.* F. B. SIMPSON AND R. G. FLUHARTY, *Phillips Petroleum Company.*—The total neutron cross sections for Sm and Gd have been measured, using a resolution of 0.04–0.07 μsec/meter, with the Materials Testing Reactor fast chopper. In order to identify those resonances due to the even-odd isotopes in these elements, samples enriched in samarium[147,149] and gadolinium[155,157] were used. The Breit-Wigner parameters have been obtained for these isotopes in the energy region 10–100 ev for samarium and 1.0–50 ev for gadolinium. The value of $\bar{\Gamma}_n^0/D$ determined for Sm^{147} is $(6.0\pm1.5)\times10^{-4}$ and $(2.0\pm0.2)\times10^{-4}$ for Gd^{155}. Information will also be presented on $\bar{\Gamma}_n^0/D$ for Sm^{149} and Gd^{157}. The $\bar{\Gamma}_\gamma$'s which were obtained are 49±10 mv and 105±15 mv for Sm^{147} and Gd^{155}, respectively.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

NA8. Distribution of Level Spacings of Heavy Nuclei.* J. A. HARVEY,† D. J. HUGHES, AND V. E. PILCHER,‡ *Brookhaven National Laboratory.*—The distributions of the spacings between slow neutron resonances in a particular nuclide have been investigated for many target nuclei, both zero and non-zero spin. The transmission curves have been carefully examined in order to correct the experimental distributions of spacings for the loss of small resonances, assuming a Porter-Thomas[1] reduced neutron width distribution. The differential spacing distributions of four zero-spin target nuclides (for which all levels in the compound nucleus have spin ½) have been combined to attain higher statistical accuracy. The resultant differential distribution of 40 spacings is exponential, as expected for random spacing, for spacings greater than half the average, but there are definitely too few small spacings: a level "repulsion" effect. There are considerable data on the level spacings in odd-A nuclei; the interpretation is complicated because two independent spin systems are present. However, the distribution determined from zero-spin nuclides has been modified to apply to the two-spin case and has been compared with the data for odd-A nuclei.

* Work performed under contract with U. S. Atomic Energy Commission.
† Now at Oak Ridge National Laboratory.
‡ Now at Union College.
[1] C. E. Porter and R. G. Thomas, Phys. Rev. **104**, 483 (1956).

NA9. Resonance Parameters of Dysprosium.* R. L. ZIMMERMAN, *Brookhaven National Laboratory.*—The neutron cross sections of separated dysprosium isotopes† have been measured with the Brookhaven fast chopper. Data-taking was facilitated greatly by use of a new 1000-channel time-of-flight analyzer designed by Higinbotham and Graham. The average transmission of thin samples in the kilovolt region gives[1] the strength function $\langle\Gamma_n^0/D\rangle - 1.7\pm0.4\times10^{-4}$ for Dy^{161} and $1.3\pm0.3\times10^{-4}$ for Dy^{163}. Parameters for about 25 individual resonances at lower energy are being obtained by the usual methods of area analysis. Those obtained thus far are shown in Table I.

TABLE I.

Isotope	E_0 (ev)	Γ_γ (mv)	Γ_n (mv)
163	1.71	103±10	1.48 ±0.12
161	2.72	118±30	0.615±0.070
161	3.69	112±45	1.62 ±0.15
161	4.33		0.96 ±0.18
162	5.45	174±45	21±7

* Work performed under contract with U. S. Atomic Energy Commission.
† Separated isotopes recently made available by the U. S. Atomic Energy Commission Isotopes Division.
[1] D. J. Hughes and V. E. Pilcher, Phys. Rev. **100**, 1249(A) (1955).

NA10. Nuclear Radius by Potential Scattering.* K. K. SETH, D. J. HUGHES, R. L. ZIMMERMAN, AND V. E. PILCHER,† *Brookhaven National Laboratory.*—The potential scattering cross section σ_p has been measured in the ev and kev regions by two different methods. In the ev region, where resonances are well resolved and their parameters known with reasonable accuracy, σ_p was determined by subtracting the calculated contribution of resonances from the total cross section. In the kev region, average transmissions T were determined with different thicknesses of the sample and corrections made for the contribution of the resonances. The slope, $(d/dn)(\log T_{hr})$, in the region where self-absorption effects and the "window" effects minimize the resonance contribution, gives σ_p directly. Typical results are

Element:	Nb	Sn	Pb	Th	U
σ_p (barns):	6.2 ±0.1	4.35±0.05	11.3±0.2	11.8±0.7	10.7 ±0.4
$R' = (\sigma_p/4\pi)^{\frac{1}{2}}$:	7.02±0.05	5.90±0.03	9.5±0.1	9.7±0.3	9.25±0.2

A comparison of R' thus determined is made with the predicted R' and nuclear radius R of the recent calculations of Feshbach, Porter, and Weisskopf,[1] using a diffuse edge cloudy crystal ball model.

* Work performed under contract with U. S. Atomic Energy Commission.
† Now at Union College.
[1] V. F. Weisskopf, Amsterdam Conference on Nuclear Reactions, June, 1956.

NA11. Determination of the 2200 m/sec Capture Cross Section of Gold Based on Measurements of the Total Cross Section from 5–11.5 A.* F. GOULD, T. I. TAYLOR, B. M. RUSTAD, E. MELKONIAN, AND W. W. HAVENS, JR., *Columbia University and Brookhaven National Laboratory.*—The total neutron cross section of gold has been determined in the wavelength interval from 5–11.5 A using the Columbia University crystal spectrometer at the Brookhaven reactor. The spectrometer was calibrated using the accurately known wavelength of the Bragg cutoff for the (111) planes in crystalline silicon, $d = 3.1354$ A. The consistency of this calibration was checked at several wavelengths using the beryllium oxide and bismuth breaks. The conclusion is that the wavelength is known to ±0.01 A over the range from 4 to 11.5 A. At 6.27 A the resolution of the instrument is 1.8% full width at half-maximum. The number of atoms per square centimeter in the gold was determined by measuring the weight and area of the portion which was actually exposed to the neutron beam. The straight line which best fits the experimental data is $\sigma_T = (54.50\pm0.02)\lambda - (0.11\pm0.68)$ barns. The value of the capture cross section can be obtained at 2200 m/sec from these data by correcting for the 4.906-ev resonance and the thermal

inelastic scattering. This leads to a value of $\sigma_c(2200\ \text{m/sec}) = 98.8 \pm 0.03$ barns where the stated uncertainty represents the standard deviation of the result.

* This work was partially supported by the U. S. Atomic Energy Commission.

NA12. Brookhaven Cold Neutron Facility.* I. PELAH, C. M. EISENHAUER, D. J. HUGHES, AND J. PALEVSKY, *Brookhaven National Laboratory.*—Preliminary experiments performed with a beam of pile neutrons emerging from the BNL reactor have shown that fundamental information concerning the spectrum of lattice vibrations in solids can be obtained by studying the energy spectrum of the neutrons scattered by solids. The principle difficulty encountered in the initial measurements was the low counting rate. In these experiments the energy of the incident neutrons is very low (~0.003 ev) and for this reason the angular spread of the incident beam can be made rather large without sacrificing resolution. To accomplish this a facility was constructed on the top of the Brookhaven reactor (where the shielding is removable) which allows the sample under study to subtend a 9° cone at the neutron radiating surface, located about 1 ft outside of the lattice. In this region the thermal flux is peaked and the fast flux is falling rapidly. In order to reach this part of the reactor from the top of the pile a 16 in. diameter hole 28 in. deep was drilled into the graphite reflector. The thermal flux measured at the position of the sample is 3×10^8 nv. The cadmium ratio is ~200, and the ratio of counting rates (1/v detector) for Be filtered neutrons to thermal neutrons is 6%.

* Work performed under contract with U. S. Atomic Energy Commission.

FRIDAY MORNING AT 9:30

Empire Suite

(C. H. TOWNES presiding)

Molecules

P1. Effects of High Pressure on the Near-Ultraviolet Absorption Spectra of a Number of Cata-Condensed Hydrocarbons. W. W. ROBERTSON, O. E. WEIGANG, JR., AND F. A. MATSEN, *The University of Texas.*—The effects of hydrostatic pressures up to 6000 atmospheres on the near-ultraviolet absorption spectra of benzene, naphthalene, anthracene, phenanthrene, naphthacene, 1, 2 benzanthracene, chrysene, and 1, 2, 5, 6 dibenzanthracene in solution in a nonpolar solvent have been obtained. In all cases the wavelength of absorption shifts to the red linearly with the increasing dielectric constant or density of the pressurized solvent. The frequency shift of the weak ^1L_b bands for a given change in the dielectric constant or density of the solvent is small and relatively constant from compound to compound. The frequency shift with density $(\Delta\nu/\Delta\rho)$ for the ^1L_a and ^1B_b bands increases in magnitude linearly with the oscillator strength (f) of the band, $-\Delta\nu/\Delta\rho = mf + b$. An attempt has been made to interpret the data in terms of the London treatment of the dispersion forces between molecules. However, the evaluation of the expression for the frequency shift requires a knowledge of oscillator strengths of all transitions involving the excited state. Since these are not available only an approximate expression can be obtained. Several different approximations are considered, none of which is found to be completely satisfactory.

P2. Interaction of Vibrational and Electronic Motion in Alkali Halide Molecules. R. STEPHEN BERRY, *Harvard University.*—Certain excited electronic states of the alkali halide molecules may display behavior corresponding either to unusually large coupling between electronic and nuclear vibrational motions or to a breakdown of the noncrossing rule. A theoretical treatment of this phenomenon for sodium and potassium iodides leads to results which are in accord with the observed ultraviolet spectra of the two compounds. In particular, it is shown that the first strong absorption continuum of KI results from a violation of the noncrossing rule and that the line spectrum of NaI, which results from the same kind of excitation process that produces a continuum with KI, indicates very strong coupling between electronic and nuclear motions in the excited state.

P3. Electronic Wave Functions for the Hydrogen Fluoride Molecule. LELAND C. ALLEN, *M. I. T.*—A number of calculations using the M. I. T. high-speed digital computer, Whirlwind, have been made to describe the electronic structure of hydrogen fluoride. Each calculation has employed the complete many-particle Hamiltonian and all ten electrons. The general aim has been to approach a Hartree-Fock solution for a polar molecule. The problem has been carried out by choosing a set of one-particle molecular basis functions, forming a determinental many-electron wave function, and varying the linear coefficients of the basis functions to minimize the energy (Roothaan procedure). The central problem is the choice of the molecular basis functions and these have been selected from both polarization and LCAO motivations. These basis functions have all been expressed in terms of a coordinate system with its origin at the fluorine nucleus. While this should be viewed primarily as a mathematical convenience, it has also allowed the determination of a binding energy for a separation of molecular constituents into either neutral F + H atoms or the ions $F^- + H^+$. Reasonable values for the binding energy and a quite good value for the dipole moment (less than 20% error) have been obtained. In addition, we have gotten a lower total energy (0.58% error) than any of the various electronic wave functions previously obtained for hydrogen fluoride.

P4. Excitation of OH Bands in Oxygen-Hydrogen or Hydrocarbon Flames. G. DÉJARDIN, J. JANIN, AND M. PEYRON, *Université de Lyon.*—The vibration-rotation $^2\Pi - ^2\Pi$ bands of OH occur in all the hydrogen flame, but only in the *outer cone* of the CH_4, C_2H_2, and C_2H_2 flames. For all fuels, the line reversal temperature differs little, in the *outer cone*, from the value obtained by observing the rotational distribution within the $^2\Sigma^+ - ^2\Pi$ band of OH. But the rotational temperature is lower than in the *inner cone*, the difference increasing from CH_4 to C_2H_2. These facts are consistent with the hypothesis that, in the *reaction zone* of hydrocarbon flames, a chemical process involving carbon compounds is responsible for the formation of OH ($^2\Sigma^+$). The reaction would impart high rotational energy, but partial deactivation by collision would lower the rotational temperature; the rise of the latter with increasing addition of nitrogen is significant. In the hydrogen flame and the *outer cone* of hydrocarbon flames, the rough concordance of the two temperatures, joined to the fact that dilution causes a fall of the rotational temperature, seems to show that OH is electronically excited in a three-body collision giving just enough energy for allowing OH to reach the $^2\Sigma^+$ state. The formation

and vibrational excitation of OH ($^2\Pi$) do not appear to have a thermal origin; the reaction: $O+H+O_3\cdots OH$ ($^2\Pi$ exc.) $+O_2$ ($^1\Sigma_g^+$) is in conformity with our observations.

P5. Active Nitrogen at High Pressure.* **J. F. Noxon,** *Harvard University.*—An afterglow of several seconds in very pure nitrogen, excited at atmospheric pressure with an ozonizer, was first found by D. G. Bills at this laboratory. At all pressures between 2 and 76 cm the afterglow spectrum shows the characteristic vibrational distribution for the first positive system favoring $v'=11$ almost exclusively, in contrast with the findings of Stanley.[1] Near atmospheric pressure radiation from long-lived metastable states becomes more intense than the first positive system and consists of the Vegard-Kaplan system of molecular nitrogen, the atomic nitrogen line 3466 A and, despite prolonged purification, the atomic oxygen line 5577 A. All three decay more slowly in time than the first positive system. Vegard-Kaplan radiation from $v'=1$ decreases relative to $v'=0$ during the lifetime of the afterglow and with increasing pressure. Collisional electronic deactivation of the A state molecules must therefore be very infrequent, and the radiative lifetime of this state must be at least of the order of one second for such vibrational deactivation to be apparent over a period of several seconds. Absolute intensity measurements indicate that the majority of metastable N atoms (theoretical lifetime 4 sec) survive from the discharge.

* Research supported by Air Force Cambridge Research Center.
[1] Stanley, Proc. Phys. Soc. (London) **A67**, 821 (1954).

P6. Nuclear Mass Ratios and Magnetic Effects in CO.* **B. Rosenblum and A. H. Nethercot, Jr.,** *Columbia University.*—Nuclear mass ratios determined from molecular spectra must be corrected for the contribution of higher electronic states induced by the rotation of the molecule. This correction can be made through a measurement of the molecular magnetic moment.[1-3] To this end, measurement of the rotational frequencies of six isotopic species of CO have been made to an accuracy of about 0.004 Mc near 110 000 Mc and measurements of the magnetic moment of four isotopic species to an accuracy of about ½%. The correction to the nuclear masses calculated from the magnetic moment reduces the discrepancy between the presently measured $C^{14}-C^{12}$ mass difference (the worst case) and the mass difference calculated from nuclear reaction data from approximately 300 micro-mass units to about 40 micro-mass units. This remaining discrepancy is far outside the errors involved. A preliminary investigation of the effects of higher order perturbations on the electrons fails to disclose any explanation for this anomaly.

* Work supported jointly by the Signal Corps, the Office of Naval Research, the U. S. Atomic Energy Commission, and the Air Research and Development Command.
[1] M. W. P. Strandberg, *Microwave Spectroscopy* (Methuen and Company, Ltd., London, 1954).
[2] Townes and Schawlow, *Microwave Spectroscopy* (McGraw-Hill Book Company, Inc., New York, 1955), Chap. VIII.
[3] B. Rosenblum and A. H. Nethercot, Jr., Bull. Am. Phys. Soc. Ser. II, 1, 13 (1956).

P7. Microwave Spectra of Molecules Exhibiting Internal Rotation. I. Propylene. **David R. Lide, Jr., and D. E. Mann,** *National Bureau of Standards.*—The microwave spectrum of propylene, $CH_3CH{:}CH_2$, has been studied in the 17 000–36 000 Mc region. The spectrum is characteristic of a rigid asymmetric rotor except that most transitions are split into close doublets as a result of internal rotation of the methyl group. The observed splittings vary from 0.2 to 0.9 Mc. Preliminary values of the reciprocal principal moments of inertia are 46 520, 9308, and 8131 Mc for the normal isotopic species and 45 580, 9307, and 8104 Mc for the species in which C^{13} is substituted for the middle carbon atom. Measurements of the Stark effect give an electric dipole moment of 0.366D. The splittings of the rotational lines are fitted very well by the theory of Hecht and Dennison.[1] The analysis leads to a value of 689 cm^{-1} (1970 cal/mole) for the potential barrier to internal rotation. This result is in excellent agreement with the value obtained from thermodynamic measurements.[2]

[1] K. T. Hecht and D. M. Dennison (private communication).
[2] J. E. Kilpatrick and K. S. Pitzer, J. Research Natl. Bur. Standards **37**, 163 (1946).

P8. Microwave Spectra of Molecules Exhibiting Internal Rotation. II. Methylallene. **D. E. Mann and David R. Lide, Jr.,** *National Bureau of Standards.*—The microwave spectrum of methylallene (1, 2-butadiene), $CH_3CH{:}C{:}CH_2$, has been investigated and all parallel transitions of the $J=1\rightarrow2$, $2\rightarrow3$, and $3\rightarrow4$ groups assigned. Most of the lines show small splittings (0.2–2.5 Mc) from the internal rotation of the methyl group. The splittings are fitted very well with the theory of Hecht and Dennison.[1] The analysis leads to a potential barrier of 556 cm^{-1} (1590 cal/mole). This result is in very good agreement with the value determined from thermodynamic measurements.[2] The reciprocal principal moments of inertia are 34 100, 4202, and 3928 Mc. A dipole moment of 0.40D has been obtained from the Stark effects.

[1] K. T. Hecht and D. M. Dennison (private communication).
[2] J. G. Aston and G. J. Szasz, J. Am. Chem. Soc. **69**, 3108 (1947).

P9. Foreign Gas Pressure Broadening of OCS.* **L. J. Kieffer and A. V. Bushkovitch,** *Saint Louis University.*—Previous calculations, using the Anderson theory, made by K. L. Perkins and the present authors[1] of the collision diameters of OCS with He, O_2, and N_2O, using the $J=1\rightarrow2$ line of OCS, were in reasonable agreement with experiment, and indicated that the perturbing molecule could be treated classically in the case of foreign gas broadening. Two new calculations also using the Anderson theory, have been carried out which support that assumption. The collision diameter of OCS with O_2 has been recomputed treating the O_2 molecule classically but including terms which were dropped in the previous calculation due to the complexity and apparent smallness of the terms. The new value, 5.48 A, is only slightly larger than that previously reported, 5.41 A. In the second calculation the perturbing molecule was treated quantum-mechanically. Closed expressions were derived for S_2 and the partial cross section. The value obtained for the collision diameter was 5.61 A which is within three percent of the value obtained treating the perturbing molecule classically.

* Supported by the Air Force Office of Scientific Research.
[1] Perkins, Bushkovitch, and Kieffer, Bull. Am. Phys. Soc. Ser. II, 1, 13 (1956) (to be published in *The Journal of Chemical Physics*).

P10. Vaporization Processes of Titanium and Aluminum Carbides.* **W. A. Chupka,** *Argonne National Laboratory,* **and Joseph Berkowitz and Mark G. Inghram,** *University of Chicago.*—The importance of gaseous metal carbide molecules has recently come into question. To answer such questions we have applied the mass spectrometer to the determination of the composition of the vapor effusing from graphite Knudsen cells containing (1) titanium or (2) aluminum. In the former case the vapor was found to consist of Ti(g), C(g), $C_2(g)$, and $C_3(g)$. TiC(g) was not detected, but if present was less than 1% of the total vapor pressure. X-ray diffraction studies of the material removed from the cell at the end of an experiment showed that most of the graphite had been converted to TiC and that no free titanium remained. From the measured vapor pressures of Ti(g) and C(g) the heat of formation of TiC(g) was calculated using 170 kcal/mole as the heat of sublimation of carbon. This result is in good agreement (within 2 kcal/mole) with the heat of formation obtained by Humphrey and serves as an indirect check on the heat of sublimation of carbon. Studies of the system Al-C has shown Al(g) to be the predominate species in the vapor phase with an ion of mass 78 also present. From appearance potential, isotopic structure and shutter studies, we have tentatively ascribed this ion to an Al_2C_2 molecule effusing from the cell.

* Supported in large part by a grant from the Office of Ordnance Research.

FRIDAY MORNING AT 9:30

North Ballroom

(S. A. SCHAAF presiding)

Fluid Dynamics, I

PA1. Ablation of Meteorites. JOHN S. RINEHART, *Smithsonian Astrophysical Observatory.*—A meteorite enters the earth's atmosphere at high velocity (8 km/sec to 70 km/sec), suffers rapid loss of material through aerodynamic heating and abrading forces, but survives passage and finally comes to rest on the ground. The ablation of high-velocity missiles is a most complex fluid dynamics problem. Post mortem examination of meteorites can suggest salient aspects of the problem. Surface features of a large number of meteorites have been studied. Very little can be said about the total amount of material lost. Meteorite size and material are critical factors. Small (up to 3 inches in diameter) meteorites are smoothly sculptured; large stones exhibit shallow elongated pits or depressions (2 cm by 1 cm by 5 mm deep); and large irons, very deep pits (5 cm in diameter and 3 cm deep. The number, distribution, and size of the depressions on a particular surface or portion of surface depends upon how the surface element is oriented with respect to direction of flight. Pronounced irregularities of shape increase ablation. Finally, heat from the surface penetrates at most only a few millimeters into the meteorite.

PA2. Estimation of the Surface Area of Porous Solids from Gas Flow Data. JOHN L. STEPHENSON, *National Heart Institute.*—It has previously been shown that if $f_1, \cdots f_n$ are the transport probabilities of a gas molecule through n separate conductors, the compound probability for the conductors arranged in series is given by $1/f = \sum_{i=1}^{n} 1/f_i - (n-1)$. Utilizing this result we show that for a thickness of porous media x, f_x is of the order of l/x, where l is the average mean free path of a gas molecule between collisions with the surface of the solid. Combining this with the Clausius formula for the mean free path $l = 4U/S$, where U is the free volume and S is the surface area per unit volume, gives as an estimate for the surface area $S = 4kU/f_x x$, where k is a dimensionless constant of the order of unity whose exact value depends on the mean free path distribution and scattering law in the particular solid. The application of this theory to the determination of the surface areas of proteins, by drying from the frozen state, will be discussed.

PA3. Recent Observations of Slip in Rarefied Gas Flows.* F. C. HURLBUT AND E. MERLIC,† *University of California, Berkeley.*—Values of the tangential momentum transfer coefficient σ have been determined from measurements of drag in a rotating cylinder apparatus. Laminar flows of various pure gases and of air at pressures in the range 15 to 250 microns Hg were established between concentric cylinders. Values of the momentum transfer coefficient were found to be dependent on the pressure history of the apparatus. When the cylinder surface was held at 0.01 micron Hg for a period of several days, values of σ of approximately 0.9 were measured for air. When the surface was held at a pressure of 250 microns, Hg values of σ were found to decrease with time reaching approximately 0.6 after a number of days. These results are considered in light of other available evidence including that obtained from measurements of molecular scattering at the surface in a molecular beam apparatus.

* Work jointly supported by the Office of Naval Research and the Office of Air Research.

† Now at Lockheed Aircraft Company, Sunnyvale, California.

PA4. On Convergence to *N*-Wave Flow. D. H. STEININGER AND F. D. BENNETT, *Ballistic Research Laboratories.*—An analytical expression for the fringe shift in the N-wave of a slender, supersonic projectile has been obtained by the authors and reported in a previous paper.[1] Under suitable approximations this expression yields an approximate mapping function, which accurately characterizes the N-wave flow. The validity of both representations for the fringe shift is quantitatively confirmed by comparison with measurements from an interferogram of a small sphere at Mach number 1.29. N-wave flow is shown to exist around the sphere for radial distances r greater than 70 sphere diameters. Measurements of the shock waves from the sphere and from a cone-cylinder show that the shocks assume their asymptotic positions at radial distances greater than fourteen diameters for the sphere and seven diameters for the cone-cylinder.

[1] D. H. Steininger and F. D. Bennett, Bull. Am. Phys. Soc. Ser. II, 1, 227 (1956).

PA5. Time-Function Ensembles in Hydromagnetic Turbulence.* ROBERT H. KRAICHNAN, *New York University.*—The equations of motion of incompressible hydromagnetic turbulence are taken as

$$L_i \equiv \dot{q}_i - \lambda \Sigma_{j,k} A_{ijk} q_j q_k + \nu_i q_i = 0,$$

where the q_i are suitably normalized and ordered real and imaginary parts of the independent components of the spatial Fourier coefficients of velocity and magnetic fields. The coefficients λA_{ijk} and ν_i describe, respectively, conservative nonlinear interaction of the modes and dissipation due to ohmic and viscous losses. The equations of motion do not completely specify all moments of the statistical distribution describing the turbulence. Sufficient conditions that a well-behaved ensemble of time functions $q_i(t)$ satisfy $L_i = 0$ are $\int \Lambda_{ij}(t,t)dt = 0$ where $\Lambda_{ij}(t,t') \equiv \langle L_i(t) L_j(t') \rangle$, $\langle\ \rangle$ indicates ensemble average, and the integration interval is arbitrary. These conditions involve only second, third, and fourth distribution moments. The moments must also obey generalized Schwarz inequalities to belong to a realizable distribution. The conditions described are applied to the moments derived from a turbulence model previously reported.[1]

* This research was supported by the Geophysics Research Directorate, Air Force Cambridge Research Center.

[1] R. H. Kraichnan, Bull. Am. Phys. Soc. Ser. II, 1, 341 (1956).

PA6. Diffusion in Turbulent Couette Flow. B. A. FLEISHMAN, *Rensselaer Polytechnic Institute* (introduced by J. Mayo Greenberg).—The random convection model of turbulent diffusion[1,2] is applied here to a two-dimensional turbulent Couette flow. Dimensionless variables are used. Suppose $U(x,y,t) = y + u(x,y,t)$ and $V(x,y,t) = v(x,y,t)$ are the x and y components, respectively, of the total velocity, and u and v are the turbulent velocity components; i.e., the mean flow in the x direction is proportional to y. The convection of mass in such a velocity field is governed by the equation $s_t = -[(y+u)s]_x - [vs]_y$, where $s(x,y,t)$ represents the concentration of diffusing matter. Subject to given initial conditions this equation is solved for $s(x,y,t) = s(u,v;x,y,t)$, which depends on the particular convection field $[u(x,y,t), v(x,y,t)]$ used in the equation. Now suppose that the velocity field (u,v) belongs to an ensemble of velocity fields; this ensemble constitutes the turbulent velocity field. The *mean* concentration is found by averaging $s(u,v;x,y,t)$ over the velocity ensemble. In the simple ensemble used here each member has constant components u, v, both u and v having Gaussian probability densities. Results are obtained for certain initial conditions.

[1] B. A. Fleishman, Quart. Appl. Math. **14**, 145–152 (1956).
[2] B. A. Fleishman, Bull. Am. Math. Soc. **62**, abstract no. 526 (1956).

PA7. Decay and Spectra in Isotropic Turbulent Reactions.* S. CORRSIN, *The Johns Hopkins University.*—Analytical studies of isotropic turbulent mixing of a scalar field[1,2] have been extended to include effects of concomitant chemical reactions. For limiting cases or strongly simplifying restrictions, estimates have been made of mean conversion rates and fluctuation decay rates.[3] Some additional conjectures are now made on consequences of the double correlation equations and on the spectra of concentration fluctuations.

* Supported by the Office of Naval Research.
[1] S. Corrsin, J. Appl. Phys. **22**, 469 (1951).
[2] S. Corrsin, J. Aeronaut. Sci. **18** (June, 1951).
[3] S. Corrsin, Symposium on Fluid Mechanics in Chemical Engineering, American Chemical Society, Purdue University, December 27–28 (1956).

PA8. Interaction of a Turbulent Air Boundary Layer with Water Waves.* BRUCE L. HICKS AND CLIVE G. WHITTENBURY, *University of Illinois.*—The motion of wind over natural bodies of water is generally turbulent. The nature of the wind-wave interaction is therefore determined by the characteristics of a turbulent boundary layer of air as it moves over the rough water surface, and in particular by the value of the ratio (δ/a) obtaining at any time and place, where δ is the boundary layer thickness and a is the rms wave height. We have found[1] that the "roughness elements" affecting the turbulent boundary layer correspond to the small water waves. The threshold speed (14 knots) for whitecapping may then be interpreted as the speed at which these roughness elements are first exposed to the full drag of the laminar sublayer. (An estimated lower limit to the whitecap density, based on a consideration of wave stability, shows no threshold wind speed.) In the transition region a dimensional analysis indicates that the drag coefficient is proportional to the $\frac{1}{4}$ power of the fetch.

* Work performed under a Joint Services contract with the U. S. Signal Corps.
[1] B. L. Hicks and C. G. Whittenbury, Control Systems Laboratory Report R-84 (1956).

PA9. Characterization of Small Wind Waves.* CLIVE G. WHITTENBURY, GEORGE S. NEWELL, AND BRUCE L. HICKS, *University of Illinois.*—Except for studies of slope distribution,[1] oceanographic literature contains almost no quantitative investigations of the structure of the small wind waves which control such variously important phenomena as wind drag and radar back scattering. We have therefore developed, as part of a program of wind wave study, a capacitance wave probe[2] which permits accurate recording of wind speed, wave height, or wave energy resident in any band of the spectrum of small waves. The probe capacity, linearly dependent on wave height, modulates the repetition rate of a blocking oscillator which generates a Miller run down wave form and triggers a boxcar to measure the run down depth. The latter provides an output proportional to wave height over a dynamic range of 1000:1 and with a sensitivity limited by interference of the smallest waves by the probe. Recent data obtained with the instrument will be discussed.

* Work performed under a Joint Services contract with the U. S. Signal Corps.
[1] C. Cox and W. Munk, J. Marine Research **13**, 198 (1954).
[2] B. L. Hicks and C. G. Whittenbury, Control Systems Laboratory Reports R-83, R-84 (1956).

PA10. Dust as a Transient Boundary Layer Indicator. RAYMOND J. EMRICH, *Lehigh University,* AND JOHN R. BANISTER, *Sandia Corporation.*—Blast from the detonation of high explosive over desert soil raises dust at quite large distances beyond the fireball. Fast motion pictures taken of the flow 100 feet away from ground zero and within a few feet of the ground show that dust begins to rise immediately behind the shock but is confined to a thin wedge-shaped layer making an angle of only a few degrees with the ground. The sharply distinguished top of the layer seen in the motion pictures and studies of the amount of dust at various heights by sampling techniques suggest a mechanism other than simple diffusion for the dust elevation. Other studies in a shock tube show that lycopodium powder on glass moves parallel to the surface under a force comparable to free stream drag. Since the flow behind a shock moving into still air does not involve turbulence in the free stream, the transient boundary layer so formed may furnish a more ideal experimental situation for study than do steady-flow arrangements. The use of dust as an indicator is promising for such studies.

PA11. Key Flow Patterns of Transition in Boundary Layers. JOHN R. WESKE, *University of Maryland.*—Comparative investigations and analysis of the chain of flow phenomena constituting the process of transition on flat plates with, or without, pressure gradient and in pipes have lead to the identification of certain patterns which are of generic significance, no matter whether transition arises spontaneously or whether it is stimulated by two- or three-dimensional impulses. One particular pattern has been singled out for detailed study because it embodies the mechanism for production of motion of wavelengths of lower order than any observed in the antecedent breakdown motion of laminar flow. Under conditions defined experimentally this motion assumes random character and in spreading from its local origin renders the boundary layer turbulent.

PA12. The Effect of Leading Edge Bluntness on Transition at Supersonic Speeds. PAUL F. BRINICH (introduced by J. Evvard).—It has been found at Mach 3.1 that small amounts of bluntness at the leading edge of an aerodynamic body have marked effects on the location of transition from laminar to turbulent flow. For a body with a two-dimensional boundary layer, transition was displaced downstream by a factor of three when the leading edge was blunted sufficiently. For a conical body a smaller downstream displacement of transition was observed. These displacements have been associated with the formation of a layer of reduced velocity near the surface produced by total pressure losses through the detached leading edge shock wave. A study of the effect of bluntness shape showed that below a bluntness Reynolds number of 20 000–40 000 the bluntness shape was unimportant. Above this value favorable or adverse effects of bluntness could be obtained, depending on the shape.

FRIDAY AFTERNOON AT 2:00

North Ballroom

(C. M. TCHEN presiding)

Fluid Dynamics, II

Q1. Rocket-Excited High-Temperature Wind Tunnel.* R. W. BOGLE AND F. K. HILL, *The Johns Hopkins University.*—Current trends in the field of high energy flows indicate the utility of an experimental facility producing high velocity streams at thermal equilibrium for aerodynamic and materials testing. A small, high-temperature wind tunnel using a solid

propellant rocket source has been developed which provides a stream velocity of 6500 ft/sec in a test section of 4.9 in.[2] at atmospheric pressures. The supply conditions of 2500°K and 67 atmos produce a sufficiently high energy transfer to the flow to obtain thermal equilibrium in the test section within five or six seconds. Model temperatures revealed by spectrographic and other techniques have been near 2200°K. The techniques of measuring Mach-number and recording shock patterns show a stable uniform stream at $M \approx 4.15$. Real gas effects including vibrational excitation of the molecules and its influence on aerodynamic measurements, the reaction of materials including surface phenomena and high rates of heat transfer are described. The present flow time has been limited to ten seconds and an increase to 45 sec seems feasible, together with plans to enlarge the test section and extend the range of flow velocities to 10 000 ft/sec.

* This work was supported by the Bureau of Ordnance, Department of the Navy.

Q2. One-Dimensional Unsteady Motion of Magneto-Gasdynamics. C. M. TCHEN, *National Bureau of Standards.*—Riemann's work on the problem of the one-dimensional expansion of an interstellar gas cloud into a vacuum is extended to include the effect of a transverse magnetic field. The gas is compressible, but the viscosity and the heat conduction are not considered. The effective velocity of propagation is the resultant of two parts: the velocity of sound due to the adiabatic expansion of the gas, and the velocity of propagation contributed by the magnetic field. The case of $\gamma = 2$ reduces the problem to Riemann's formulation, while for $\gamma = 5/3$ a generalized Riemann's equation is found. The method of Lagrangian coordinates is used for the case of a more general γ.

Q3. Calculation of the Blast Wave from a Spherical Charge of TNT.* HAROLD L. BRODE, *The RAND Corporation.*—The numerical solution of the partial differential equations of hydrodynamic motion resulting from the centered detonation of a spherical charge of TNT was accomplished in a manner similar to some previous problems by the author with the aid of a high-speed computer. The equation of state of the TNT (loading density 1.5 g/cc, net energy release 247.9 kcal/mole) was approximated from data by Jones and Miller, while the equation of state for air was taken as a fit to data from several sources as reported previously. The initial conditions of the detonation wave in the TNT were as specified by Taylor. The results clearly show the details of the main shock in air, the rarefaction into the high explosive followed by an inward moving shock, the various reflections of this inward shock, and refractions at the contact discontinuity. Slides will be presented showing peak overpressure and other shock values such as peak particle velocity, peak dynamic pressure, shock density, and shock temperature as functions of the shock radius. Pressures, velocities, densities, and temperatures at various distances as a function of time will be shown, as will also radial profiles of the same quantities at specific times. Some comparison will be made with the point-source explosion in air.

* The work involved in this study was supported entirely by the U. S. Air Force.

Q4. Production of Strong Cylindrical Shock Waves by Exploding Wires. R. C. O'ROURKE, V. SCHERRER, AND C. B. DOBBIE, *U. S. Naval Research Laboratory.*—Strong cylindrical ingoing and outgoing shock waves (~1 cm/μsec at S.T.P. in air) are produced by electrically exploding small diameter wires (~4000 joules dumped into circuit in less than 1 μsec). Results will be presented on preliminary measurements of (1) Radii *vs* time measurements of luminous phase of both ingoing and outgoing shocks. (2) Spectral luminosity *vs* time. The wires are mounted along the axis of a cylindrical chamber (3 cm in length and 1.7 cm diameter). The data was obtained from pictures taken with a Bowen strip-film camera (speed 3 mm per μsec). A Tobe-Deutschmann condenser (100 kv, 0.85 μfarad, 0.08 μhenries) was used as an energy source for the explosions. The time duration of the well-known discharge "pause-phenomena," which occurs below about 20 kv, was observed to decrease significantly as the voltage was increased to 100 kv.

Q5. Shock Tubes with Area Change at the Diaphragm Section. D. R. WHITE AND R. A. ALPHER, *General Electric Research Laboratory.*—The strength of a shock wave generated in a shock tube is modified by an area change at the diaphragm section. The magnitude of this effect has been studied on an ideal basis in the case of either subsonic or supersonic cold flows. A rather general method of presenting the results of such calculations will be discussed. Some comparisons with experiment will be made. Earlier work on the modification of shock tube flows by a convergence at the diaphragm section will be clarified.

Q6. Shock Tube Study of Dissociation Relaxation in Oxygen.* H. S. GLICK AND W. H. WURSTER, *Cornell Aeronautical Laboratory, Inc.*—A schlieren optical system and a high purity level shock tube have been used to study relaxation phenomena in oxygen at temperatures from 1200°K to 4000°K. Vibration and dissociation relaxation zones have been observed, and the data has been correlated with other experiments and existing theory. The measured vibrational relaxation times are in reasonable agreement with those measured by Blackman up to 3000°K. At higher temperatures, another nonequilibrium zone appears which is believed to be due to dissociation relaxation. The dissociation relaxation times, however, are several orders of magnitude shorter than those predicted by the theory of Bethe and Teller. The short dissociation relaxation times observed in the present experiments are corroborated by chemical kinetics studies of the formation of nitric oxide, and it is therefore believed that the theoretical model of dissociation kinetics for oxygen requires refinement. Theoretical studies, based on the work of Rice, are being carried out in an effort to reconcile theory and experiment.

* Supported by the Office of Scientific Research.

Q7. Magnetically Driven Shock Waves.* A. C. KOLB, *U. S. Naval Research Laboratory.*—By coupling strong external magnetic fields to a low-inductance, high-voltage discharge extremely strong shock waves with Mach numbers greater than $M = 100$ can be produced with energies of the order 400 ev per ion.[1] In this paper a discussion of recent measurements of the dependence of the shock velocity on the discharge voltage and inductance will be presented. Some theoretical results on the broadening of the HeI, 3889 A line will also be given, together with preliminary observations of the time-resolved spectrum of magnetically driven shock waves. The broadening of the 3889 A line shows an interesting red asymmetry that is due to the presence of both ions and electrons in the plasma. Above ~50 000°K the concentration of HeI is negligible relative to the concentration of HeII and cannot be observed.

* This work was jointly supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

[1] A. C. Kolb, Winter Meeting, American Nuclear Society (December, 1956).

Q8. Interferometric Measurements of the Laminar Boundary Layer on a Shock Tube Wall.* J. R. RUETENIK AND L. V. DIVONE,† *M. I. T.* (introduced by Joseph Kaye).—Interferometric measurements of the growth of the laminar boundary layer on the wall of the MIT-WADC 8- ×24-in. shock tube were carried out over a range of Reynolds number up to 10^7, and a particle Mach number up to 0.7. The measurements are compared to the theory of Mirels and others. A

careful study was made of the optical effect introduced by the refraction of the light rays in the boundary layer and tunnel windows, and suggestions are given for future experiments.

* This investigation was sponsored in part by the Wright Aeronautical Development Center, Aircraft Laboratory.
† Now associated with California Institute of Technology.

Q9. Comparison of Trimpi-Cohen Shock Tube Theory with Density Measurements.* RAYMOND GOLDSTEIN, *Lehigh University* (introduced by D. B. Wheeler, Jr.).—Using the chrono-interferometer method[1] measurements were made on the time variation of density in the hot gas at two different positions in a 3.5-cm diameter shock tube. Weak shock waves ($P_{41}=2$) in nitrogen were studied. The results obtained indicate that for positions not too far from the diaphragm there is good agreement with the Trimpi-Cohen[2] theory of shock tube flow. A comparison by Wheeler[3] of the measurements of Mack on shocks of higher strength gives only order of magnitude agreement with the theory. These results would be expected since the theory is derived on the assumptions of low shock strength and small distance from the diaphragm.

* Supported by the Office of Naval Research.
[1] Curtis, Emrich, and Mack, Rev. Sci. Instr. **25**, 679 (1954).
[2] R. L. Trimpi and N. B. Cohen, "A theory for predicting the flow of real gases in a shock tube with experimental verification," NACA TN 3375 (1955).
[3] D. B. Wheeler, Jr., "Density variation in shock tube flow," Lehigh University Tech. Rept. 8 (1956).

Q10. On the Application of Shock Tube Experiments to the Study of Compressible Boundary Layers.* ROBERT G. JAHN AND JOHN R. ASBRIDGE, *Lehigh University.*—One of the Lehigh shock tubes is designed specifically for the investigation of the effects of the bounding walls on the gas flow behind the incident shock. The tube has an internal cross section of $4\times\frac{1}{2}$ in. which provides an abnormally large surface to volume ratio. A Mach-Zehnder interferometer takes spark photographs through $1\frac{1}{4}\times\frac{1}{2}$ in. windows transverse to the 4-in. dimension, thereby providing density maps of large portions of the full field—two boundary layers and the free stream—in the essentially two-dimensional flow behind the shock. The experimental conditions available in this brief section of "uniform" flow compare favorably with the more familiar steady flow situations. For example, this particular tube can produce a range of free stream Reynolds numbers from 9×10^3 to 1.1×10^6 cm^{-1} in nitrogen, at pressures from 10 mm to 12 000 mm of Hg. In addition, the free stream portion of the flow is totally free of background turbulence. Experimental observations of density variations, both in the boundary layers and free stream, taken over the above range of conditions will be presented and discussed.

* Supported by the Office of Naval Research.

Q11. Experiments on Interaction between Traveling Shock Wave and Turbulent Jet.* DARSHAN S. DOSANJH,† *Johns Hopkins University* (introduced by F. N. Frenkiel).—The interaction of a turbulent jet and a plane shock wave traveling in a shock tube was optically observed. Various arrangements of both subsonic and supersonic jets were used. As a direct result of its passage through the jet, the shock wave developed a bulge. The growth and behavior of this bulge were recorded through a sequence of instantaneous shadowgraphs. The transverse spread and the changing profile of this bulge offer an interesting visual demonstration of the angle of spread and decay of the jet flow. It is shown that beyond an equivalent distance of about twelve jet diameters the bulge-profile reaches a state of similarity. When the shock and the jet impinged against each other head on, an intense, intermittent and high-frequency acoustic radiation manifested itself in the flow field behind the shock front. Some plausible explanations of this phenomenon will be advanced.

* This work was supported jointly by the Bureau of Ordnance and U. S. Air Force.
† At present at Syracuse University.

FRIDAY AFTERNOON AT 2:00

Terrace Room

(B. CHALMERS presiding)

Symposium of the Division of Solid-State Physics
Imperfections Produced by Crystal Growth

QA1. Crystal Growth from the Melt. W. A. TILLER, *Westinghouse Research Laboratories.* (2:00 to 2:40)

QA2. Production and Removal of Imperfections in Semiconductor Crystals. W. G. PFANN, *Bell Telephone Laboratories.* (2:50 to 3:15)

QA3. Observations of Dislocations in Silicon Crystals Grown from the Melt. W. C. DASH, *General Electric Laboratories.* (3:25 to 3:50)

QA4. Effect of Growth Variables on Gross Imperfections in Nonmetallic Crystals. P. H. EGLI, *U. S. Naval Research Laboratory.* (4:00 to 4:25)

QA5. The Detection of Imperfections in Crystals. B. L. AVERBACH, *M. I. T.* (4:35 to 5:00)

FRIDAY AFTERNOON AT 2:00

Boston-Washington Room

(L. ONSAGER presiding)

Theoretical Physics IV: Statistical Mechanics, Collective Motions

R1. An Information Theory Treatment of the Destruction and Emergence of Order. HUBERT P. YOCKEY, *Oak Ridge National Laboratory.*—Information theory is concerned with order in systems capable of being ordered. Suppose λ is a measure of an influence which affects the order of a system. Let $p_i(j)$ be the transition probability from state i to state j

and assume that the rate of change of $p_i(j)$ with respect to λ is proportional to $p_i(j)$ plus a constant required by normalization. It is possible to show that

$$dH_x(y)/d\lambda = -J(\lambda)H_x(y) - \frac{J(\lambda)}{N}\sum_{i,j} p(i)\log_2 p_i(j),$$

using notation given by Shannon.[1] This equation plus the equations for the $p_i(j)$ can be solved for $H_x(y)$ with due regard for the boundary conditions. The final measure of the order of the system is given by Shannon's channel capacity theorem $R = H(y) - H_x(y)$.

[1] Claude E. Shannon and Warren Weaver, *The Mathematical Theory of Communication* (University of Illinois Press, 1949).

R2. Aspects of the Probability Assumptions in Statistical Mechanics. K. R. JONES AND M. DRESDEN, *University of Kansas.*—To study in some detail the specific assumptions of a probability nature made in statistical mechanics, Kac[1] has constructed a simple model, allowing a complete mathematical analysis. In Kac's model, n balls, white and black, move around a circle consisting of n equidistant points. Some of these points are marked. When a ball leaves a marked point, it changes color. The problem is to find the color distribution of the balls after t steps, for a given initial distribution. The probability notions are introduced by averaging over the set of markers. The following points appear to be of special importance: the usual Stosszahlansatz type assertion, even after averaging, is valid only in the limit of n infinite. In fact, for a finite n, the averaged solution of the Liouville equation is still periodic, whereas the solution of the Master equation approaches equilibrium monotonically. However, if one subjects the markers to an average process after each step, the Liouville equation yields solutions identical with those of the Master equation. Models in which both the markers and the balls move are being studied.

[1] M. Kac, Bull. classe sci., Acad. roy. Belg. Ser. 5, 356 (1956) and M. Kac, unpublished sequel to foregoing.

R3. Integrated Power Absorption by Coupled Oscillators.* C. CIMERMAN AND J. S. LEVINGER, *Louisiana State University.*—We have calculated the power absorption in the steady state, integrated over all frequencies (P_{int}) for coupled, damped linear oscillators driven by a periodic force. For the special case of a single oscillator of mass m driven by a sinusoidal force of amplitude F_0, we find $P_{\text{int}} = \pi F_0^2/4$ m. This result is well known[1] for very high-quality factor Q; we have shown that it holds for any Q and that P_{int} is independent of the resonance frequency for free oscillations. We find this same value for P_{int} when the driven oscillator of mass m is linearly coupled to other damped linear oscillators. In our proof, we uncouple the simultaneous differential equations for the case that the damping matrix commutes with the restoring force matrix.

* Assisted by the LSU Council on Research.
[1] For example, A. H. Compton and S. K. Allison, *X-Rays in Theory and Experiment* (D. Van Nostrand and Company, New York, 1935), p. 290.

R4. Statistical Analysis of the Anisotropic Oscillator. MARTIN L. GURSKY, *Los Alamos Scientific Laboratory.*—We choose an anisotropic oscillator potential, $V = \frac{1}{2}m\omega^2\xi^2$, where $\xi^2 = \sum x_i^2\beta_i^2\{\beta_i = \exp[-\alpha\cos(\gamma - 2\pi j/3)]\}^1$ defines the family of all ellipsoids. ξ = constant defines the family of all ellipsoids with constant volume equal to $(4/3)\pi\xi^3$. Assuming ω to be independent of α and γ, we may write for the kth energy level (in units of $\hbar\omega$): $E^{(k)} = \mathbf{m}^{(k)}\cdot\boldsymbol{\beta}$, where $\mathbf{m}^{(k)} = (n_i^{(k)} + \frac{1}{2})$, $\boldsymbol{\beta} = (\beta_i)$. A simple statistical analysis leads to the general results that, for an ensemble of particles subject to the Pauli principle, the number of particles with energy less than or equal to E is $(1/3)E^3$, while their total particle energy is $(1/4)E^4$—both results independent of shape. Among the consequences of this result for a nuclear model are the following: (1) The anisotropic oscillator particle energy contains little, if anything, which can be interpreted as surface energy. (2) Assuming the height of the Fermi "sea" approximately independent of A, (a) the radius of the resultant particle distribution is proportional to $A^{\frac{1}{3}}$ while (b) the particle energy is proportional to A.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.
[1] D. L. Hill and J. A. Wheeler, Phys. Rev. **89**, 1102 (1953), Fig. 13.

R5. Magnetic Scattering of Neutrons by Exchange-Coupled Lattices above the Transition Temperature. A. W. SÁENZ, *U. S. Naval Research Laboratory.*—We treat the elastic and inelastic scattering of neutrons of energy $Eo \lesssim kT$ by exchange-coupled lattices whose transition temperatures $Tc \ll T$, using the word exchange to denote ordinary exchange as well as superexchange. We take into account the exchange coupling Jnn' between two arbitrarily distant paramagnetic ions, n and n', and the temperature motion of the lattice. Combining the formalism of van Hove[1] with standard operator techniques we (a) express the differential cross section $d\sigma_{\text{mag}}/d\Omega$ and suitably defined moments $\bar{\epsilon}^n$ ($n = 1, 2, \cdots$) of neutron energy transfer as power series in $(Jmm'/kT)^r \cdot (Jnn' \sim Eo)^s (r, s = 0, 1, 2, \cdots)$; (b) compute $d\sigma_{\text{mag}}/d\Omega$, $\bar{\epsilon}$, and $\bar{\epsilon}^2$ for $r + s \leq 2$ for zero phonon processes; (c) estimate the magneto-vibrational scattering and relate it to the inelastic incoherent phonon scattering. A brief comparison will be given with an earlier theoretical attempt of Slotnick[2] as well as with data of Brockhouse[3] on antiferromagnetics at $T \gg Tc$.

[1] L. van Hove, Phys. Rev. **95**, 1354 (1954).
[2] M. Slotnick, Phys. Rev. **83**, 1226 (1951).
[3] B. N. Brockhouse, Phys. Rev. **99**, 601 (1955).

R6. Generalization of the Boltzmann Transport Equation for Arbitrary Densities. JOHN M. RICHARDSON, *Hughes Aircraft Company.*—M. S. Green[1] has recently given a derivation of the Boltzmann transport equation (and generalizations thereof) using the Born-Green hierarchy as a point of departure. Here we present a quite different approach to the problem based upon a self-consistent formulation of irreversible statistical mechanics. The system considered is a classical assembly of structureless identical particles interacting with central forces. In the case of arbitrary density, the sole use of the number density in one-particle phase space is not satisfactory. One must augment this set of observables in such a way that the total energy and momentum are contained in the linear manifold associated with the new set. The one of several possibilities chosen here is the addition of the interaction energy density in one-particle phase space. The resultant phenomenological equations for the foregoing mean densities in phase space resemble nothing the author has been able to find in the literature but perhaps bear a vague resemblance to the Fokker-Planck equation. A virial-like development is presented, and some rather subtle difficulties involved in the passage to the standard Boltzmann equation are discussed.

[1] M. S. Green, Natl. Bur. Standards Rept. 3327 (August, 1955).

R7. Nonequilibrium Pair Distribution Function at Low Densities. M. S. GREEN, *National Bureau of Standards* (introduced by C. W. Beckett).—In a recent paper on the Boltzman equation,[1] the author has given a demonstration of Bogolyubov's hypothesis[2] that at low densities the nonequilibrium molecular distribution functions are functionals of the single-particle distribution which can be expressed as a power series in the density. In this talk, the explicit form of the first-order term in the functional representing the pair distribution function will be presented and some of its properties discussed.

[1] M. S. Green, J. Chem. Phys. **25**, 836 (1956).
[2] N. N. Bogolyubov, J. Phys. U.S.S.R. **10**, 265 (1946).

R8. Ground State of a System of Interacting Fermions.* LEON N. COOPER, *University of Illinois.*—The ground state energy and wave function of a system of Fermions interacting with each other in a container of volume Ω is considered in a density region which is appropriate to metals ($\sim 10^{23}$ Fermions/cm^3). An approximation is introduced which gives many-body effects in its lowest order and is believed to give a good estimate of the ground-state energy and wave function for a large class of interactions. It is shown that, for two-body interactions, one can obtain a ground state which corresponds to a condensation of the system in which the ground state is separated from the lowest unperturbed level by an energy which (depending upon the interaction) may increase as Ω or as Ω^2. Ordinary, short-range, attractive interactions can produce condensed states whose wave functions correspond to highly correlated many-particle states, which are localized in space. Application of these results to a system of electrons in a metal, and to a microscopic theory of superconductivity, will be discussed.

* This work was supported in part by the Office of Ordnance Research, U. S. Army.

R9. Coulomb Enhancement of Positron Annihilation in Metals.* J. J. QUINN AND R. A. FERRELL, *University of Maryland.*—Earlier perturbation calculations[1] on the idealized model of a degenerate electron gas with a uniform background of positive charge have been extended to second order for the special case of zero electron momentum. The results of the calculation can be compared directly with experimental lifetimes since the two-photon angular correlation measurements reveal how the total annihilation rate is distributed over electron momenta. The calculation includes the screening by the Fermi gas of the positron and of the zero momentum electron, caused by short-range correlation. The perturbation is the Bohm-Pines short-range potential acting pairwise between all charged particles but with a somewhat shorter range than determined by Pines. The range is given by the shortest wavelength plasma oscillation which can be propagated in the electron gas, a cutoff already determined in previous work.[2]

* Research supported by the Office of Naval Research.
[1] R. A. Ferrell, Revs. Modern Phys. **28**, 308 (1956). See Sec. III for further references.
[2] J. J. Quinn and R. A. Ferrell, Bull. Am. Phys. Soc. Ser. II, **1**, 44 (1956).

R10. Collective Coordinate Analysis of Free Einstein-Bose System.* J. K. PERCUS AND G. J. YEVICK, *Stevens Institute of Technology.*—Because of statistics, the Einstein-Bose free-particle system has extensive collective behavior. The scope of this collective behavior is exhibited by means of the projection of the exact wave function in configuration space onto collective coordinate axes. For low excitation, the projected wave function thus obtained coincides with that predicted by collective coordinate analysis. The physical significance of the collective coordinate constants of motion is elucidated. At high excitation, the projected wave function exhibits new properties not contained in the simple collective coordinate picture. The assumption of decomposability of the N-dimensional Q-space into two-dimensional subspaces is tested in several ways. First it is shown that at low excitation, the Q_k component of a stationary state depends only upon excitation of phonons of wave number $\pm k$. Further, projection upon a product of two-dimensional subspace yields just a product of individual projections, providing that the wave numbers represented are nearly incommensurable. Finally, the validity of the decomposition assumption is greatly improved by going over from one to three dimensions. Appropriate modification for the free Fermi-Dirac system is readily obtained, but the computations are less transparent.

* Supported by Office of Naval Research.

R11. Some New Kinds of Collective Coordinates for the Many-Body Problem.* G. J. YEVICK AND J. K. PERCUS, *Stevens Institute of Technology.*—We have been considering new types of collective coordinates which have special properties. As a simple example, consider $Q_1 = \Sigma_j V(x_1 - x_j)$. These N coordinates diagonalize the potential exactly but introduce off-diagonal kinetic energy terms which are very large for short-range forces and small for very long-range forces. Another example is the "thermal coordinate" $\eta_m = \Sigma_{|k|=m} \Sigma_i \Sigma_j \times \exp ik(x_i - x_j)$. With these coordinates, one can represent the high wave number part of the potential very well. The character of the off-diagonal terms in the kinetic energy appears satisfactory especially for long-range forces. The strategy which one can adopt is to use the usual collective coordinates $q_k = \Sigma_i \exp(ikx_i)$ for the wave-number part and the η_m for the high wave numbers. As a final example, we are also analyzing $\xi_n = \Sigma_i h_n(x_i)$, where $h_n(x_i)$ are the nth-order Hermite polynomials. These coordinates appear to be very suitable for describing nonuniform media such as the finite nucleus. A general prescription has been evolved for selecting suitable collective coordinates for different kinds of nonuniform media. This prescription insures that the off-diagonal terms in the kinetic energy are minimized.

* Supported by Office of Naval Research.

R12. Cluster Expansions and the Debye-Hückel Theory.* D. L. BOWERS AND E. E. SALPETER, *Cornell University.*—We consider a dilute gas of particles, with a two-body potential V_{ij} acting between pairs of particles at a high temperature T. V_{ij} is a long-tailed potential (e.g., Coulomb). We start from the usual classical expansion[1] in terms of irreducible clusters for the two-particle correlation function. This expansion converges very poorly because of the long range of V_{ij}, but the sum of an infinite series of certain types ("simple chain") of clusters can be expressed in terms of the solution g_{ij} of an inhomogeneous linear integral equation. The remaining cluster diagrams then can be regrouped, and an infinite series of terms is obtained, where each term is an explicit integral involving the functions g_{ij}. This new series converges rapidly if the temperature is high and the concentration is low. The first term in this series is a slight generalization of the Debye-Hückel correlation function. Applications to the effect of electron screening on thermonuclear reaction rates will be presented.

* Supported in part by a joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] J. E. Mayer and M. G. Mayer, *Statistical Mechanics* (John Wiley and Sons, Inc., New York, 1940), Chap. 13.

R13. Radial Distribution Functions by Collective Coordinates. A. A. BROYLES, *The RAND Corporation.*—Methods[1,2] have previously been devised for employing collective coordinates to evaluate such N-body integrals as those that occur in the calculation of the equation of state (classical) of ions in a plasma. These have been limited to regions of high temperature and low densities since they are equivalent to an expansion of the Jacobian in a Gram-Charlier series of collective coordinates. A method without these limitations is described here where the product of the Boltzman factor (with Coulomb interactions) with the Jacobian is expanded in the series. Otherwise, the procedure is the same as that of reference 1. This method has been used to compute the average potential energy and pair distribution function for ions in a plasma where the free electrons are replaced by a uniform negative background.

[1] A. A. Broyles, RM-1682-AEC, The RAND Corporation.
[2] G. J. Yevick and J. K. Percus (papers available at cost from the Department of Physics, Stevens Institute of Technology).

FRIDAY AFTERNOON AT 2:00

Panel Room

(W. W. BUECHNER presiding)

Nuclear Reactions and Nuclear-Energy Levels, II

RA1. Energy Levels of C^{13} from $B^{11}(He^3,p)C^{13}$. A. GALONSKY, C. D. MOAK, R. L. TRAUGHBER,* AND C. M. JONES,† *Oak Ridge National Laboratory.*—Spectra of charged particles produced in the bombardment of B^{11},[1] with 1.25-Mev He^3 ions have been observed at 45°, 90°, and 135° in a NaI-crystal spectrometer. Of the proton groups observed, those corresponding to the well-known states at 0, 3.097, 3.684, 3.844, and 6.864 Mev excitation in C^{13} were used as calibrations to determine the excitations corresponding to the other groups. After bombardment of the target had built up carbon, additional calibration peaks were available from the $C^{13}(He^3,p)N^{14}$ reaction. With these calibrations the following energies in Mev were determined for C^{13} states: 5.49 ± 0.08, 6.09 ± 0.08, 7.58 ± 0.06, 8.85 ± 0.06, 9.54 ± 0.08, 9.92 ± 0.06, 10.9 ± 0.15, 11.1 ± 0.15, 12.08 ± 0.1, and 12.81 ± 0.1. The groups corresponding to the new states at 5.49 and 6.09 Mev are each only 5 to 10% as intense as the ground state group. Both states must be narrow because they have not been seen in the $n-C^{13}$ total cross section or for the mirror nucleus, N^{13}, in the $p-C^{13}$ interaction.

* 1956 summer participant from Louisiana State University, now at Stanford University.
† 1956 summer participant from Georgia Institute of Technology.
[1] 99.3% B^{11} purchased from the Atomic Energy Research Establishment, Harwell, England.

RA2. Gamma-Ray Decay Schemes in B^{11} from the Reaction $Be^9(He^3,p\gamma)B^{11}$. A. J. FERGUSON, H. E. GOVE, A. E. LITHERLAND, E. ALMQVIST, AND D. A. BROMLEY, *Chalk River Laboratories.*—Gamma rays from the first nine excited states of B^{11},[1] have been observed from the reaction $Be^9(He^3,p\gamma)B^{11}$ at a bombarding energy of 2.1 Mev. By examining the gamma rays in coincidence with various proton groups, the spectrum from each state was studied independently with the exception of those from the 6.76-Mev and the 6.81-Mev states, for which the proton groups were not resolved. The gamma-ray transition to the ground state is observed for all of the levels. In addition, the cascade through the first excited state is observed from the 5.03-Mev, 7.30-Mev, 7.99-Mev, and 8.57-Mev states and the unresolved pair at 6.76 Mev and 6.81 Mev, generally with an intensity comparable with that of the corresponding ground state transition. From the particle spectrum coincident with gamma rays of energy greater than 7.5 Mev, it is inferred that the gamma-ray width of the 8.92-Mev level is comparable to its alpha-particle width. Gamma rays from the first excited state of B^{10} from the reaction $Be^9(He^3,d\gamma)B^{10}$ have also been observed.

[1] Bent, Bonner, McCrary, Ranken, and Sipple, Phys. Rev. **99**, 710 (1955); Sample, Neilson, Chadwick, and Warren, Can. J. Phys. **33**, 828 (1955).

RA3. Gamma Rays from Carbon Induced by He^3 Bombardment. H. E. GOVE, A. E. LITHERLAND, E. ALMQVIST, D. A. BROMLEY, AND A. J. FERGUSON, *Chalk River Laboratories.*—Gamma rays from the reactions $B^{10}(He^3,p\gamma)C^{12}$, $B^{10}(He^3,d\gamma)C^{11}$ and $C^{12}(He^3,\alpha\gamma)C^{12}$ have been studied directly and in coincidence with the corresponding particle groups using 2-Mev He^3 particles from the electrostatic generator. Proton groups in the first reaction were found corresponding to levels in C^{12} previously reported.[1] The proton group leading to the 15.10-Mev level was found to be in coincidence with a gamma ray of 15.10 Mev. For this level the ratio Γ_γ/Γ was found to be approximately unity in agreement with previous results.[2] The proton group leading to the 12.76-level in C^{12} was found to be in coincidence with gamma rays of energy >6.5 Mev. Evidence for a 12.76-Mev gamma ray in C^{12} has been reported.[3] For this 12.76-Mev level our measurement gives $\Gamma_\gamma/\Gamma\approx0.01$.[3] The 15.10-Mev gamma ray has also been observed from He. particles incident on C^{12} and is presumed to occur from the third reaction above. Deuterons from the second reaction above have been found in coincidence with 2.0 ± 0.1 Mev gamma rays and correspond to a level of this energy in C^{11}.

[1] Bigham, Allen, and Almqvist, Phys. Rev. **99**, 631(A) (1955).
[2] Hayward and Fuller, Abstract at Amsterdam Conference, July, 1956.
[3] Barnes and Kavanaugh, Phys. Rev. **100**, 1796(A) (1955) and private communication.

RA4. Gamma Radiation from the Reaction $N^{14}(He^3,p)O^{16}$-I. D. A. BROMLEY, A. J. FERGUSON, H. E. GOVE, A. E. LITHERLAND, AND E. ALMQVIST, *Chalk River Laboratories.*—Excited states of O^{16} at excitations less than 13.5 Mev have been observed in a study of the gamma radiation from the $N^{14}(He^3,p\gamma)O^{16}$ and $N^{14}(He^3,p,a,\gamma)C^{12}$ reactions at a bombarding energy of 2.1 Mev. Measurements of the direct proton spectra and of the gamma spectra, both direct and in coincidence with the corresponding proton groups, confirm the existence of the states previously observed in alpha-particle scattering on C^{12},[1] and also, of the previously reported states at 8.87 and 11.08 Mev.[2] Detailed measurements have been made on the gamma decay of these two states. The cascading from that at 8.87 Mev is in essential agreement with that reported earlier[2] and in addition the *M2* transition to the ground state was observed. In contrast, the 11.08-Mev state decays primarily to the 1^-, 7.12-Mev state and only weakly to the 3^-, 6.14-Mev state; the ground state transition is extremely weak. The 3^+ assignment to this state predicted by the alpha-particle model[4] is not supported by these measurements. The angular distributions of the gamma radiations are approximately isotropic as are the $(He^3,p\gamma)$ correlations.

[1] J. W. Bittner and R. D. Moffat, Phys. Rev. **96**, 374 (1954).
[2] W. F. Hornyak and R. Sherr, Phys. Rev. **100**, 1409 (1955).
[3] Wilkinson, Toppel, and Alburger, Phys. Rev. **101**, 673 (1956).
[4] D. M. Dennison, Phys. Rev. **96**, 378 (1954).

RA5. Gamma Radiation from the Reaction $N^{14}(He^3,p)O^{16}$-II. A. E. LITHERLAND, E. ALMQVIST, D. A. BROMLEY, H. E. GOVE, AND A. J. FERGUSON, *Chalk River Laboratories.*—Further study of the cascading of the gamma radiation in this reaction has been carried out by measuring gamma-gamma coincidence spectra using two 5×4 in. NaI(Tl) crystal spectrometers. In agreement with previous measurements,[1] only states at 8.87 and 11.08 Mev contribute to the cascading in O^{16}. Spectra in coincidence with the 7.12 and 6.91-Mev radiation showed principally radiation of energy about 1.72, 3.96, and 4.17 Mev. Similarly the spectra in coincidence with the 6.14-Mev radiation showed radiations of about 2.75 and 5.04 Mev. The measurements support a 2^- assignment to the 11.08-Mev level. The inhibition of the 4.17 and 1.90-Mev *E1* radiations accords with the isotopic spin selection rule. The gamma-gamma correlations, in contrast to the $(He^3,p\gamma)$ correlations, are markedly anisotropic and may provide direct information on the spins involved.

[1] W. F. Hornyak and R. Sherr, Phys. Rev. **100**, 1409 (1955) and previous abstract.

RA6. Differential Cross Section Measurements for $N^{14}(p,p)N^{14}$ and $N^{14}(p,p')N^{14*}$. J. W. OLNESS, J. VORONA, AND H.

W. LEWIS, *Duke University.**—A differentially pumped gas-scattering chamber containing natural nitrogen has been used to measure differential cross sections for proton scattering from N^{14} for scattering angles and proton energies (Mev) of $\theta_{cm}=168.1°\cdots1.0\leq E_p\leq4.1$, and $\theta_{cm}=90.0°\cdots1.4\leq E_p\leq4.1$. Calibration of the electrostatic proton beam analyzer against the $Li^7(p,n)Be^7$ threshold and measurement of beam energy losses in the chamber gas determine the energy scale to an accuracy of better than ±3 kev. In addition to the work reported earlier, this study yields information on a broad resonance observed by Bashkin *et al.*, having a resonance energy $E_r=3.86$ Mev and total width $\Gamma\sim100$ kev, and on two narrow resonances having $E_r=2.535$ Mev, $\Gamma<8$ kev, and $E_r=3.980$ Mev, $\Gamma<15$ kev. Additional data were obtained at scattering angles of $\theta_{cm}=39.2°$, 54.7°, 125.3°, and 140.8° to provide information on the resonance at 3.86 Mev; this study was extended down to 3.3 Mev to tie in with the data obtained by the Minnesota group. The resonances at 3.86 and 3.980 Mev exhibit an observable cross section for inelastic scattering leading to the 2.31-Mev excited state of N^{14}. The angular distribution of the inelastic protons at the 3.86-Mev resonance has the form $W(\theta)\propto A-B\cos^2\theta$, indicating the resonance is due to $1_p\geq1$ formation of a state in O^{18} having $j\geq\frac{1}{2}$.

* This work was supported by the U. S. Atomic Energy Commission.

RA7. Excited States in O^{16}. I. Neutron Thresholds in $N^{15}(d,n)O^{16*}$.† J. WEIL, K. W. JONES, L. J. LIDOFSKY, H. SMOTRICH, AND J. BAICKER, *Columbia University.*—A search was made for excited states in O^{16} using the counter ratio method[1] for detecting neutron thresholds in the reaction $N^{15}(d,n)O^{16}$. In addition to previously well-established levels, thresholds were detected at $E_d=1.192$ and 1.335 Mev corresponding to O^{16} excited states at 10.937±0.010 and 11.063 ±0.015 Mev. The 10.937-Mev state may be identified with the O^- gamma emitting state reported by Bent *et al.*[2] It also can be identified with an unassigned state recently seen in the reaction $F^{19}(p,\alpha)O^{16*}$.[3] A thin N^{15} gas target was used. Background runs using a He target filling were made to insure that these thresholds can be unambiguously attributed to $N^{15}(d,n)O^{16*}$.

† This work was partially supported by the U. S. Atomic Energy Commission.
[1] Brugger, Bonner, and Marion, Phys. Rev. **100**, 84 (1956).
[2] Following abstract.
[3] Squires, Bockelman, and Buechner, Phys. Rev. **104**, 413 (1956).

RA8. Excited States in O^{16}. II. Gamma-Emitting States below 12 Mev. R. D. BENT, T. H. KRUSE, L. J. LIDOFSKY, AND K. E. EKLUND, *Columbia University.**—A search has been made for states in O^{16} between 7.2 and 11.5 Mev of excitation which belong to the sequence 0^-, 1^+, 2^-, $3^+\cdots$. These states cannot break up into $C^{12}+\alpha$ but must decay by gamma emission. Gamma rays from the $F^{19}(p,\alpha\gamma)O^{16}$ ($E_p=5.2-6$ Mev) and $N^{15}(d,n\gamma)O^{16}$ ($E_d=4.5$ Mev) reactions were studied using a three crystal pair spectrometer. A 3.80±0.03 Mev gamma ray was observed from both of these reactions. Double coincidence measurements show that this gamma ray arises from a cascade transition between a state at 10.98±0.04 Mev and the 1^- state at 7.12 Mev. No gamma rays resulting from the decay of the 10.98-Mev state to other states of O^{16} were observed. These results suggest a spin and parity assignment of 0^- for the 10.98-Mev state. No strong gamma rays were observed corresponding to ground state transitions from excited states between 7.5 and 11.5 Mev, which suggests the absence of a 1^+ state in this region of excitation of O^{16}. A weak ground state transition from the 2^- 8.87-Mev state was observed with 0.06±0.03 the intensity of the 2.73-Mev cascade transition to the 3^- 6.14-Mev state.

* This work was partially supported by the U. S. Atomic Energy Commission.

RA9. Excited States in O^{16}. III. Excitation Function for $N^{15}(p,n)O^{15}$ Reaction. K. W. JONES, L. J. LIDOFSKY, AND J. WEIL, *Columbia University.**—The excitation function for the $N^{15}(p,n)O^{15}$ reaction has been measured for neutrons emitted at laboratory angles of 0° and 90° and for bombarding energies from threshold to 6.36 Mev and 5.97 Mev, respectively. A thin N^{15} (74%) gas target and a conventional "long counter" neutron detector were used. Absolute cross sections were estimated using a calibrated Ra-Be source. The threshold energy was found to be 3.779±0.007 Mev, in good agreement with the value obtained by Kington *et al.*[1] Resonances are observed in the excitation function. The bombarding energies in Mev and the approximate laboratory widths in kev for the resonances are: 4.37 (25), 4.5 (~150), 5.34 (45), 5.52 (80), 5.88 (75), 6.12 (90), 6.24 (50), and 6.33 (40). These resonances correspond to excited states in O^{16} at: 16.20, 16.3, 17.11, 17.28, 17.62, 17.84, 17.96, and 18.04 Mev.

* This work was partially supported by the U. S. Atomic Energy Commission.
[1] Kington, Bain, Cohn, and Willard, Phys. Rev. **99**, 1393 (1955).

RA10. Energy Levels of O^{17} from 4.0 to 5.9 Mev Excitation.* CORNELIUS P. BROWNE, *University of Notre Dame.*—Previous experiments using the $F^{19}(d\alpha)O^{17}$ reaction[1] and the O^{16} neutron total cross section[2] give conflicting information about the levels of O^{17} above 5 Mev. In the present work the MIT broad-range spectrograph was used to record the proton spectra from the $O^{16}(d,p)O^{17}$ reaction. Bombarding energies were 7.0 and 7.5 Mev and angles of observation were 30°, 60°, and 90°. Proton groups were found corresponding to levels in O^{17} at 4.553±0.008, 5.083±0.010, 5.215±0.006, 5.378 ±0.010, 5.695±0.006, 5.731±0.006, and 5.866±0.006 Mev where 1.918 Mev has been used for the ground-state Q value. The 4.55-, 5.08-, and 5.38-Mev levels have half-widths of 40, 95, and 20 kev, respectively, in good agreement with the neutron scattering results. The other levels are narrow (<8 kev). The narrow levels at 5.21 and 5.73 were not seen in the neutron scattering,[2] while the (d,α) experiment[1] failed to resolve the 5.69 and 5.73 levels and did not distinguish the broad 5.08 level from background. The other levels were seen in all three experiments.

* The data reported here were obtained with the MIT-ONR electrostatic accelerator and associated analyzers. The work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] H. A. Watson and W. W. Buechner, Phys. Rev. **88**, 1324 (1952).
[2] Bockelman *et al.*, Phys. Rev. **84**, 69 (1951).

RA11. Level Density in F^{19} as Inferred from Nitrogen Induced Reactions. CHARLES D. GOODMAN, *Oak Ridge National Laboratory.*—As a verification of the validity of deducing the density of states in a residual nucleus from the energy spectra of particles emitted from a compound nucleus, three nitrogen induced reactions involving three different compound nuclei but the same residual nucleus were compared. In particular, the energy distributions of protons from $Li^6(N^{14},p)F^{19}$, deuterons from $Li^7(N^{14},d)F^{19}$ and α particles from $Be^9(N^{14},\alpha)F^{19}$ have been measured and compared to each other. In each case more than two-thirds of the excitation energy of the compound nucleus comes from binding energy rather than incident kinetic energy, so that a statistical distribution of the energy among the nucleons seems likely. After correction for kinematical, phase space, and Coulomb differences, the energy distributions of the outgoing particles in the three reactions agree closely with each other except in the region of low-energy particles where contributions from two-step reactions are expected. The intensities of resolved levels near the ground state differ only slightly among the reactions. The level density function fits the Fermi gas formula $W(E)=C\exp2(aE)^{\frac{1}{2}}$ with $a=1\pm0.1$ Mev^{-1}.

RA12. Proton Angular Distributions from the Reaction $F^{19}(d,p)F^{20}$.* F. D. SEWARD, I. SLAUS,† AND H. W. FULBRIGHT,

University of Rochester.—The University of Rochester 27-in. variable energy cyclotron has been used to measure the angular distribution of protons from the reaction $F^{19}(d,p)F^{20}$ leaving F^{20} in the ground state. Data was taken over a range $5° \leq \theta \leq 170°$ and $3.5 \leq E_d \leq 4.1$ Mev. The angular distributions at some energies show a large peak in the backward direction. A rapid variation of shape with energy is also found. A previous measurement[1] with $5° \leq \theta \leq 95°$ was interpreted as a mixture of $l_n = 0$ and $l_n = 2$ stripping, thus fixing the ground state of F^{20} as $J = 1^+$. This new data indicates that the reaction proceeds mostly by compound nucleus formation and that a stripping interpretation, together with the F^{20} J-value assignment, is unjustified. The protons leaving F^{20} in its first excited state show a prominent $l_n = 2$ stripping curve in agreement with the previous result.

* Supported in part by the U. S. Atomic Energy Commission.
† On leave from Institut Ruđer Bošković, Zagreb, Yugoslavia.
[1] Bromley, Bruner, and Fulbright, Phys. Rev. **89**, 396 (1953).

FRIDAY AFTERNOON AT 2:30

Grand Ballroom

(S. A. KORFF presiding)

Cosmic Rays

S1. Energy Spectra of the Components of the Primary Cosmic Radiation.* S. F. SINGER, *University of Maryland.*—A detailed analysis[1] of balloon and rocket experiments was performed and included albedo and geomagnetic corrections. It reveals a significant difference in the spectrum exponents, i.e., the various primary components do *not* have the same velocity spectrum. In the relativistic portion of the latitude sensitive region we have the following results: Number of particles per m²-sterad-sec with total energy E_t per nucleon $> E_t$ is $4000E_t^{-1.15}$ (protons); $460E_t^{-1.6}$ (alphas); $40E_t^{-2.0}$ (C, N, O, and F); $30E_t^{-2.3}$ ($Z \geq 10$). An interpretation is given in terms of nuclear collisions and resulting fragmentations of heavy primaries. However any clearcut experiments which demonstrate the *absence, above* the atmosphere, of Li, Be, and B, or of H^3, H^3, and He^3 would invalidate this interpretation.

* Supported in part by the U. S. Air Force Office of Scientific Research.
[1] S. F. Singer, in *Progress in Elementary Particles and Cosmic Ray Physics* (Interscience Publishers, Inc., New York, 1957), Vol. 4.

S2. Trajectories of Cosmic-Ray and Auroral Stream Particles. C. A. PEARSE AND R. JASTROW, *Nucleonics Division, U. S. Naval Research Laboratory.*—A program has been prepared for the calculation of charged particle trajectories in the magnetic field of the earth. The trajectories are determined by numerical integration of the equations of motion on NORC, at the Naval Proving Grounds in Dahlgren. A typical trajectory requiring 500 intervals of integration is completed in approximately one minute. We are applying this program to the problem of relating solar flares to observations on the relative intensity of cosmic-ray increases over the earth's surface. Applications to auroral phenomena are also planned. Results will be presented.

S3. Effects of Spatial and Time Inhomogeneities on the Galactic Diffusion of Cosmic Rays. HOWARD LASTER,* *Cornell University.*—Using a specific model[1] for the diffusion of cosmic rays in the galaxy, one can examine the effects of spatial and time inhomogeneities. Anisotropy results from (i) in isolated region of different source strength in an otherwise uniform medium, (ii) a region acting as a sink in a uniform medium, or (iii) the near presence of a boundary to the uniform medium. In case (i) the anisotropy decreases appreciably at high cosmic-ray energies; in cases (ii) and (iii) anisotropy rises at high energies to a level predicted by a monoenergetic approximation. The effect of source strength variations in time is studied in a simplified model. Taking the sources as isolated, instantaneous bursts of particles spread randomly throughout the medium, the dependence of cosmic-ray flux changes in time upon the frequency and size of the injecting bursts is examined.

* Present address: University of Maryland.
[1] Morrison, Olbert, and Rossi, Phys. Rev. **94**, 440 (1954).

S4. Cross-Section Measurement at Very High Energy.* A. E. BRENNER AND ROBERT W. WILLIAMS, *Massachusetts Institute of Technology.*—An experiment to measure a nuclear collision cross section in iron, in the energy range of 30 to 300 Bev, was performed utilizing the cosmic rays at an altitude of 10 600 feet as a source of high-energy nucleons. Energy estimates are based on the measurement of the electronic cascade resulting from π^0 production as measured by a large rectangular double ionization chamber. Hodoscoped trays of Geiger counters distinguished single protons and neutrons entering the array. With 1493 hours of running time, the collision cross section in iron at a median energy of about 50 Bev is for neutrons $\sigma = 605 \pm 30$ mb and for protons $\sigma = 615 \pm 45$ mb. From this one finds for the effective elementary nucleon-nucleon cross section $\bar{\sigma} = 21$ mb, to an estimated accuracy of 25%; this is the meson-production or particle-production cross section. We therefore find, contrary to previous indications,[1] that the nucleon-nucleon cross section remains essentially constant at least out to about 50 Bev.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. W. Williams, Phys. Rev. **98**, 1393 (1955).

Invited Paper

S5. An Experiment on Air Showers. BRUNO ROSSI, *M. I. T.* (30 min.)

FRIDAY AFTERNOON AT 2:00

Empire Suite

(A. H. SNELL presiding)

Optical and X-Ray Spectra

SA1. Effect of Simultaneous Doppler and Collision Broadening on the Imprisonment of Resonance Radiation. P. J. WALSH, *Westinghouse Electric Corporation, Bloomfield Lamp Division.*—An expression has been derived for the persistence time of imprisoned resonance radiation when Doppler and collision broadening are present simultaneously. The influence of overlapping of the hyperfine structure is taken into account. Good agreement is found with measured persistence times in mercury.[1] The fit with experiment determines the relative decrease in the width of the collision broadened line due to the presence of the mercury hyperfine structure to be $\simeq 0.63$. Holstein[2] has estimated this reduction to be of the order of $\frac{1}{3}$.

[1] Alpert, McConbrey, and Holstein, Phys. Rev. **76**, 1257 (1949).
[2] T. Holstein, Phys. Rev. **72**, 1212 (1947).

SA2. Quantum-Mechanical Theory of Pressure Broadening. MICHEL BARANGER, *Carnegie Institute of Technology and The RAND Corporation.*—A theory will be presented for the pressure broadening of spectral lines, where the motion of the perturbers is treated by quantum mechanics. This is appropriate for use with electron perturbers when the wavelength is so large that the classical path approximation cannot be made. The results are simple only in the familiar "impact approximation" limit which, however, is almost always adequate for dealing with electrons. Inelastic collisions between electrons and the light-emitting atom are considered. Degeneracy of the atomic states is also taken into account. But the natural width of the line is assumed negligible, compared to the pressure broadened width, since this is usually the case in practice. Under these conditions, the line has a Lorentz shape, whose width and shift are given rather simply in terms of the elastic scattering amplitudes of an electron by the atom in one of the two states that combine to emit that particular line. Alternatively, the two inelastic cross sections may be introduced in the expression for the width. Thus, the problem is reduced to the standard quantum-mechanical problem of scattering an electron by an excited atom. Differences between this and other theories of electron broadening will be discussed.

SA3. Pressure-Induced Satellites.* LEWIS KLEIN (introduced by H. Margenau).—A qualitative suggestion by Preston[1] and others is utilized in an attempt to formulate a quantitative theory of the side bands accompanying the absorption lines of the alkali spectra. In accordance with that hypothesis a suitable set of interaction energy curves for the radiating atom-perturber configuration were chosen; and the statistical theory as formulated by Margenau[2] was used. It is shown that a very general set of potential energy curves cannot lead to results in agreement with the data of Ch'en[3] or Robin.[4] It is suspected that the statistical theory (in its present formulation) does not account for the satellite band phenomena, no matter how peculiar the interaction curves may be, and that a model including the perturber motions (now under study) is required to explain the facts.

* Work supported by U. S. Air Force Research and Development Command.
[1] W. M. Preston, Phys. Rev. **51**, 298 (1937).
[2] H. Margenau, Phys. Rev. **40**, 387 (1932); **44**, 931 (1933).
[3] Ch'en, Bennet, and Jeffimenko, J. Opt. Soc. Am. **46**, 182 (1956).
[4] J. Robin and B. Vodar, Compt. rend. **242**, 2330 (1956).

SA4. Optical Spectra Excited in Noble Gases by Charged Particles.* W. R. BENNETT AND C. S. WU, *Columbia University,* AND V. W. HUGHES, *Yale University and Columbia University.*—A restudy of the spectra previously observed in helium and argon using a spectrometer with increased resolution and sensitivity showed that the lines were mainly due to a small nitrogen impurity in the gas samples. The transitions observed in the presence of helium consisted primarily of first negative bands of the N_2^+ molecule, whereas those observed in the presence of argon were second positive bands of the N_2 neutral molecule. This is a particularly striking effect in that the nitrogen bands persisted at intensities of up to 60 times the intensities of the normal atomic transitions for conditions where the nitrogen impurity concentration was estimated to be less than one part in 10^5. It was found that the excitation energies for the highest N_2^+ and N_2 states observed corresponded to the energy available from the metastable states in helium and argon, respectively. Therefore, the excitation of such small amounts of N_2 impurity must occur by collisions with the long-lived metastable states, which in turn are nonradiatively excited by the charged particles. This process appears to predominate over both direct excitation and radiative recombination. Thus a gas scintillation counter based on the effect of metastables would be relatively slow.

* This work was partially supported by the U. S. Atomic Energy Commission.

SA5. Hyperfine Structures of the Resonance Lines of Indium (In^{115}). D. A. JACKSON, *Laboratoire A. Cotton, C.N.R.S., Bellevue, France.*—The hyperfine structures of the two visible resonance lines of the arc spectrum of In^{115}, $5\,^2P_{\frac{1}{2}}-6\,S_{\frac{1}{2}}$, 4511 A and $5\,^2P_{\frac{3}{2}}-6\,S_{\frac{1}{2}}$, 4101 A, have been measured in the absorption of a multiple atomic beam of high collimation, the emission background being provided by a water-cooled hollow cathode discharge. The spectroscopic instrument of high resolving power was a double Fabry-Perot etalon, with a spectral range of 500 mK and a limit of resolution of 0.2 to 0.3 mK (1 mK = 0.001 cm^{-1}); the combined instrumental and Doppler width of the lines was less than 5 mK. The necessary measures were taken to avoid systematic errors, and the random error was reduced by making more than 50 independent measurements of the structures of both lines; the probable error in the determinations of the hfs intervals was thus made substantially smaller than 0.1 mK, an accuracy comparable with that obtainable by the microwave method. The hfs intervals found for the three terms involved are:

$5\,^2P_{\frac{1}{2}}$: 58.53, 37.35, and 22.19±0.07 mK
$5\,^2P_{\frac{3}{2}}$: 380.65±0.05 mK.
$6\,S_{\frac{1}{2}}$: 281.16±0.05 mK.

These values are in agreement with those found (for the P terms) by the microwave method, to within the combined probable errors.

SA6. Correction of Complex Spectra for Instrumental Resolving Power. Part I.* L. G. PARRATT AND C. F. HEMPSTEAD,† *Cornell University.*—A complex spectrum always shows greater contrast, and often more detail, after correction for the finite resolving power (i.e., for the "spectral window") of the spec-

trometer. The clearer view usually justifies considerable effort in an attempt to correct the direct measurements. The correction procedure herein described is applicable to any observed spectrum, *however complex*, but is limited to certain model window shapes. The procedure involves an arbitrary analysis of the observed spectrum into *virtual* components each having a shape given by a particular functional form. This functional form depends upon the shape of the spectral window since we seek a practical mathematical "unfolding" process. A practical process is one for which there exists a unique explicit expression for the parameters of the virtual components of the corrected (or true) spectrum in terms of those of the virtual components of the observed spectrum. Then, with the parameters obtained from the observed spectrum, the corrected curve is readily synthesized. Two model windows, *viz.*, a Lorentzian (classical dispersion function) and a Gaussian (normal distribution function) are discussed with an example procedure given for each case.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.
† Now at the Bell Telephone Laboratories.

SA7. Correction of Complex Spectra for Instrumental Resolving Power. Part II.* J. O. PORTEUS AND L. G. PARRATT, *Cornell University.*—In Part I (preceding abstract) the general problem is stated and a solution outlined for certain model windows. Now we give a different solution, one having greater practical generality. The observed spectrum is regarded as a superposition of the true spectrum and a perturbation function. The present solution is practical in almost all actual cases; however two formal conditions must be met: (a) a unique solution must exist and (b) the perturbation function must be expressible as a series of "correction functions" having uniformly decreasing amplitudes. These correction functions are calculated directly by taking successive "folds" (convolutions) of the spectral window (assumed to be known) with the observed spectrum. The calculation can be readily performed on a digital-type computer, or even on a desk calculator if a low order of correction is satisfactory. Estimates of the accuracy of the corrected spectrum, point by point, are provided by the correction functions themselves. Illustrative examples are given for an ideal simple spectrum and for complex x-ray emission and absorption spectra as observed with a two-crystal spectrometer.

* Supported by the U. S. Air Force through the Office of Scientific Research of the Air Force Research and Development Command.

SA8. Refractive Index of Helium Vapor.* M. H. EDWARDS, *Royal Military College of Canada.*—The refractive index n of saturated helium vapor has been measured from 1.5 to 4.2°K, using a Jamin interferometer and a metal cryostat with optically flat windows. Over 170 experimental points were taken. For $\lambda = 5461$ A, $(n-1)$ increases smoothly from $(3.1\pm0.2)\times10^{-6}$ at 1.5°K to $(329.0\pm1.3)\times10^{-6}$ at 4.2°K. Eight separate absolute determinations of $(n-1)$ were made over this temperature range and the results combined with the calculated vapor density[1,2] to give the polarizability per mole $N_0\alpha$. The mean polarizability per mole is 0.1245 ± 0.0001. Individual determinations from 1.8° to 4.2° do not deviate from this by more than 0.0008. This value should be compared with $0.1245_4\pm0.0000_2$ which may be calculated from the measurements[3] of $(n-1)$ for helium gas at NTP.

* Supported by the Defence Research Board of Canada.
[1] R. A. Erickson and L. D. Roberts, Phys. Rev. **93**, 957 (1954).
[2] R. Berman and C. A. Swenson, Phys. Rev. **95**, 311 (1954).
[3] C. Cuthbertson and M. Cuthbertson, Proc. Roy. Soc. (London) **A135**, 40 (1932).

SA9. Measurement of the Gold and Mercury K X-Rays Using the 7.7-Meter Bent Crystal Spectrometer.* ROBERT K. SMITHER, BERNARD HAMERMESH, AND DAVID ROSE, *Argonne National Laboratory.*—In the course of our investigation of the capture gamma-ray spectrum from gold with the Argonne 7.7-meter bent-crystal spectrometer,[1] we have observed the detailed K-x ray spectrum from gold and the $K\alpha_1$ line from mercury. Using our secondary method of energy measurement which is accurate to 1 part in 10^3 we find the following energies (in kev) for the K-x rays from gold: $K\alpha_1 - 68.72$, $K\alpha_2 - 66.92$, $K\beta_1 - 77.47$, $K\beta_2$ doublet -80.11, $K_{O_{II}O_{III}}$ doublet -80.82. From mercury only the $K\alpha_1$ line with energy 70.70 kev is observed. The $K\alpha_2$ line and $K\beta$ lines from mercury are obscured by the much more intense gold lines. The values quoted agree within our limits of error with Ingelstam's[2] values for gold and the mercury $K\alpha_1$ value agrees with Saxon's[3] value.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Hamermesh, Rose, and Smither, Bull. Am. Phys. Soc. Ser. II, **1**, 346 (1956).
[2] E. Ingelstam, Nova Acta Regiae Soc. Sci. Upsaliensis (1946) **4**, No. 5.
[3] D. Saxon, thesis, University of Wisconsin, 1954 (unpublished).

SA10. Double Transitions in Metals Soft X-Ray Spectra. JEAN PIRENNE AND PIERRE LONGE, *University of Liège, Belgium.*—Line shape modifications due to inelastic interelectron collisions are found comparable for sodium to those due to elastic collisions considered by Landsberg,[1] in sharp contradiction with previous statements that the influence of the first process, suggested by Mott[2] and Cady and Tamboulian,[3] is entirely negligible. Both types of collisions lead to a broadening of each monochromatic contribution produced by a one-electron transition in the conventional Bloch scheme. For Landsberg's mechanism however, this broadening is symmetric and predominant for the low-frequency side of the emission band, whereas for the presently studied Mott's mechanism, the broadening is asymmetric and predominant near the high-frequency edge. Consequently, both processes create a tailing of the emission band towards low frequencies, but the first one alone gives rise to an appreciable broadening, both of the high-energy edge of this band and of the absorption discontinuity. From the asymmetry of this broadening, some small discrepancy might possibly result between the experimental values of these two frequencies which would strictly coincide following the conventional interpretation in terms of single electron transitions. Comparison with experiment will be discussed.

[1] Landsberg, Proc. Phys. Soc. (London) **62A**, 806 (1949); Skinner, Trans. Roy. Soc. (London) A **239**, 95 (1940).
[2] N. F. Mott (private communication).
[3] W. M. Cady and D. H. Tamboulian, Phys. Rev. **59**, 381 (1941).

SA11. Absorption of 96-Mev X-Rays. J. MOFFATT, J. THRESHER, AND RICHARD WILSON,* *Oxford University.*—96-Mev x-rays from the Oxford Synchrotron have been used for a precise measurements of absorption cross sections. The detector is a large liquid scintillator biased to detect only large pulses. The effective photon energy is determined by measuring the counts as a function of synchrotron peak energy and was 96 ± 1.5 Mev. The results are

$\sigma_H/\sigma_{Cu} = 7.944\pm0.010$ $\sigma_{Pb}/\sigma_{Cu} = 6.533\pm0.007$ $\sigma_{Ta}/\sigma_{Cu} = 2.436\pm0.003$
$\sigma_C/\sigma_{Cu} = 0.0599\pm0.00013$ $\sigma_{Cu} = 4.866\pm0.028$ barns
σ_H by $C-CH_2$ difference $= 20.8\pm0.5$ millibarns
σ_H by liquid H_2 target $= 19.22\pm0.35$ millibarns.

The results for heavy elements show the deviation from the Born approximation, but the deviation is a little smaller than recent theory which applies only at extreme relativistic energies. The value of σ_H is a little larger than current theoretical belief.

* Now at Harvard University.

FRIDAY EVENING AT 7:00

Terrace Room

(E. P. WIGNER and W. C. MICHELS presiding)

Banquet of the APS and the AAPT

Award of the Oliver E. Buckley Solid-State Physics Prize to Charles Kittel

After-Dinner Speeches

The Work and Environment of the Physicist Yesterday, Today, and Tomorrow. M. J. KELLY, *Bell Telephone Laboratories.*

A Nuclear Physicist's Impressions of Russia. R. R. WILSON, *Cornell University.*

SATURDAY MORNING AT 9:30

Terrace Room

(R. C. FLETCHER presiding)

Semiconductors, I

T1. On the Decay of Current Carriers in Semiconductors. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—It is shown that the exponential decay of electron and hole concentrations conventionally derived by making a linear approximation in the recombination equation ($dn/dt = dp/dt = g - rnp$) becomes a hyperbolic tangent or cotangent relaxation law in some important cases when that particular approximation is not made. The laws derived are a direct consequence of bimolecular kinetics. The effect of interpretation of lifetime measurements and related effects can be large. Detailed discussion is given of pair relaxation in intrinsic semiconductors with or without external pair generating mechanisms. It is shown that extrinsic carriers affect recombination parameters but not the form of the relaxation law. In some cases of importance both for phosphors and semiconductors the same laws are preserved in the presence of trapping. The importance of ambipolar diffusion is indicated for semiconductors. An explicit solution of the steady state one-dimensional diffusion equation with bimolecular processes ($Dd^2n/dx^2 + g - rn^2 = 0$) is indicated, involving elliptic functions. Experiments are described which verify the predicted relationships.

T2. Influence of Electric Field in Diffusion Region upon Breakdown in Germanium *n-p* Junctions. E. M. PELL, *General Electric Research Laboratory.*—The high current density existing at near-breakdown reverse bias of an *n-p* junction produces, by Ohm's Law, an electric field. If the effect of this field is included in the solution of diode current, it is found that it can significantly affect the breakdown characteristic. It can, for example, produce an increase in injected photocurrent resembling multiplication, even though multiplication is not occurring in the junction itself. Alternatively, if multiplication is present, it can produce instability and breakdown before the avalanche in the space-charge region itself becomes unstable (i.e., before the multiplication factor becomes infinite). These predicted phenomena have been observed in a series of germanium *np* junctions. Closely allied with these phenomena is the observation of a region of "soft breakdown" in many germanium junctions, which appears to be a bulk effect.

T3. Field-Dependent Mobility in Space-Charge-Limited, Majority-Carrier Current Theory. MURRAY A. LAMPERT, *RCA Laboratories.*—Recent data of Gunn[1] for *n*-type germanium show a field-dependence of electron mobility at relatively low fields. It thus appears to be a general requirement of realistic calculations in current flow problems that they incorporate field-dependent mobilities. For a substantial class of problems involving space-charge-limited, majority-carrier currents the calculations can be carried out analytically with *any* polynomial representation: $\mu_0 \mathcal{E}/v_d = 1 + A_1 v_d + \cdots + A_n v_d^n$. Here μ_0 is the low-field mobility, $\mathcal{E}$ the electric-field intensity, and v_d the drift velocity. Up to fields of 400 v/cm, Gunn's room temperature data is accurately represented with just the linear term with $A_1 = 0.047 \times 10^{-6}$ (v_d in cm/sec). At higher fields further terms are necessary. Results will be given for a semiconductor problem previously analyzed with restrictive assumptions by Shockley and Prim[2] and Dacey[3] and for problems of interest in insulator physics.

[1] J. B. Gunn, J. Electronics **II**, 87 (1956).
[2] W. Shockley and R. C. Prim, Phys. Rev. **90**, 753 (1953).
[3] G. C. Dacey, Phys. Rev. **90**, 759 (1953).

T4. Seebeck Effect in Zinc Oxide. A. R. HUTSON, *Bell Telephone Laboratories.*—The Seebeck effect has been measured for single crystals of *n*-type ZnO over the temperature range 60°K to 300°K. The crystals, grown from the vapor phase, are needles of hexagonal cross section, about 0.2 mm in diameter and 1 cm in length. The measurement technique makes use of a thermal analog to a potentiometer in order to obtain the crystal temperature at the electrical contacts. The measurements show a very large contribution to the thermoelectric power, Q, from the "phonon-drag" effect first observed in germanium by Frederikse and by Geballe. The "phonon-drag" contribution, Q_p, to Q is obtained by subtraction of the electronic contribution, Q_e, which is calculated from Hall effect measurements and a knowledge of the "density-of-states" electron mass $m^{(N)}$.[1] Q_p depends upon temperature approximately as $T^{-2.5}$ for relatively pure samples with values as high as 1200 μv/deg at 300°K and 30 000 μv/deg at 80°K. The behavior of Q_p is at least qualitatively in agreement with Herring's theory.[2]

[1] A. R. Hutson, Bull. Am. Phys. Soc. Ser. II, 1, 381 (1956).
[2] Conyers Herring, Phys. Rev. **96**, 1163 (1954).

T5. Thermoelectricity and Conduction in InSb. T. H. GEBALLE, *Bell Telephone Laboratories.*—Measurements of the thermoelectric power, Q, and the thermal conductivity K, for *p*-type InSb from liquid helium to intrinsic temperatures show the following behavior. For 2×10^{18} excess acceptors per cc a large Q_p, the phonon drag contribution to Q, is observed as reported by Frederikse and Mielczarek.[1] Q_p equals 4800 μv per degree at 30°K and varies as $T^{-2.4}$ up to 70°K. This temperature dependence, the boundary scattering effect, and a saturation effect observed in less pure material are under-

standable in terms of Herring's[2] theory. K falls off as T^{-3} above its maximum of about 16 w units at 11°K. This more rapid temperature dependence than K for germanium is believed indicative of less isotopic scattering. The following observations, which have been found previously in silicon and germanium, respectively, are believed due to an impurity band-phonon interaction. (1) Q varies much more rapidly with temperature than theoretically expected[2] for pure material in the boundary scattering range. For 2×10^{16} excess acceptors Q reverses sign and becomes negative below 4°K where no Hall effect can be detected. (2) K for that sample varies as $T^{4.6}$ between 2° and 3°K.

[1] H. P. R. Frederikse and E. V. Mielczarek, Phys. Rev. **99**, 1889 (1956).
[2] C. Herring, Phys. Rev. **96**, 1163 (1954).

T6. Magnetic Field Dependence of the Hall Coefficient and Electrical Conductivity in Semiconductors.* J. H. BECKER, *National Bureau of Standards.*—The spherical energy surface approximation used by Johnson and Whitesell[1] to calculate the Hall coefficient and electrical conductivity when mixed ion-lattice scattering is present in a one-carrier or intrinsic semiconductor, has been extended to include arbitrary number of bands and concentrations. The formulas reduce to those of Willardson, Harman, and Beer[2] for a system of electrons, fast and slow holes with lattice scattering. When mixed ion-lattice scattering is present in a many-band system, the magnitude of the Hall coefficient and the electrical conductivity as well as their rate of change with magnetic field can be considerably reduced compared to when only lattice scattering is present. The large contributions of the light mass carriers (i.e., light holes in p-type germanium[2]) to the Hall coefficient and magnetoresistance are most easily reduced by small amounts of ion scattering. Under some conditions the change of the Hall coefficient with magnetic field can even be opposite to that which would take place if only lattice scattering were present.

* Research supported in part by ONR and OSR.
[1] V. A. Johnson and W. J. Whitesell, Phys. Rev. **89**, 941 (1953).
[2] Willardson, Harman, and Beer, Phys. Rev. **96**, 1512 (1954).

T7. Low-Temperature Hall Mobility of PbS, PbSe, and PbTe. R. S. ALLGAIER, *U. S. Naval Ordnance Laboratory and University of Maryland,* AND W. W. SCANLON, *U. S. Naval Ordnance Laboratory.*—The Hall coefficient and resistivity of about 20 samples of PbS, PbSe, and PbTe have been measured between 4.2° and 300°K. In all cases, the Hall mobility μ_H calculated from this data increased over the entire temperature range, as the samples were cooled. At 4.2°K, the mobilities reached ranges of 25 000–70 000, 40 000–200 000, and 200 000–750 000 cm²/v-sec for PbS, PbSe, PbTe, respectively. The carrier concentration in most of the samples is about 10^{18}/cm³, so that the mobility values are in sharp contrast to those in a Ge sample of similar carrier concentration ($\mu_H\simeq1000$). A possible explanation for the high mobilities will be presented. Also, the differences between the low-temperature mobility behavior in natural and synthetic PbS crystals, and the effects of heat treatment on the mobility of some samples will be discussed.

T8. Hall Effect in p-Type Germanium and Silicon. DONALD LONG AND ALLEN NUSSBAUM, *Honeywell Research Center.*—Measurements were made of Hall coefficient *vs* temperature between 100°K and 300°K at fields of 220, 1750, and 7650 gauss on an 8 ohm-cm sample of p-type germanium. The results are in general agreement with the ideas of Willardson, Harman, and Beer.[1] The Hall coefficient over the same temperature range at 33 gauss exhibits a small positive temperature dependence. Curves of Hall coefficient *vs* temperature between 150°K and 320°K on 18 and 35 ohm-cm B-doped p-type silicon samples show nearly identical negative temperature dependences[2] at 1750 and 7850 gauss, and the Hall coefficients are practically independent of field up to 7850 gauss at 77°K and 290°K. Transverse magnetoresistance was also measured *vs* field strength on the 35 ohm-cm sample; magnetoresistance mobility is field-independent up to 7850 gauss at 290°K and decreases with increasing field above about 2000 gauss at 77°K. These results are discussed on the basis of known valence band properties.

[1] Willardson, Harman, and Beer, Phys. Rev. **96**, 1512 (1954).
[2] F. J. Morin and J. P. Maita, Phys. Rev. **96**, 34 (1954).

T9. Photoelectromagnetic (PEM) Effect in InAs. J. R. DIXON AND A. D. KRUMBEIN,* *U. S. Naval Ordnance Laboratory.*—Kurnick and Zitter have proposed a theory which describes the *PEM* effect for large as well as small Hall angles.[1] When applied to InAs their theory indicates that the relationship between the magnitude of the *PEM* signal and the corresponding magnetic induction should be linear for n-type material but should show a saturation effect for p-type material. Experimental data will be presented which verify these predictions. Values for the minority carrier mobility in p-type material have been calculated on the basis of this saturation effect. Data pertaining to the effect of etching on the magnitude of the *PEM* signal will be presented. Values for typical surface recombination velocities will also be given. The ratio of the photoconductive to the photoelectromagnetic responses has been used to calculate bulk lifetimes.[1,2]

* Now at Nuclear Development Corporation of America.
[1] S. W. Kurnick and R. N. Zitter, J. Appl. Phys. **27**, 278 (1956).
[2] W. van Roosbroeck, Phys. Rev. **101**, 1713 (1956).

T10. Interband Magneto-Optic Effects in Semiconductors. E. BURSTEIN AND G. S. PICUS, *U. S. Naval Research Laboratory.*—In a magnetic field, the intrinsic absorption edge of InSb shifts to shorter wavelengths and the absorption spectrum exhibits several pronounced absorption peaks which are attributed to transitions between magnetic sub-bands of the valence and conduction bands. These interband magneto-optic (*IMO*) effects are related to cyclotron resonance in the same way that the Zeeman effect is related to paramagnetic resonance. Both the *IMO* effect and cyclotron resonance involve a diamagnetic coalescence of the quasicontinuous levels of energy bands into one-dimensional magnetic sub-bands. However, the *IMO* effect involves transitions between magnetic sub-bands of different electronic energy bands, whereas cyclotron resonance involves transitions between magnetic sub-bands of the same energy band. The corresponding magnetic effect ion the photoionization spectra of impurities will involve both the magnetic splitting of the impurity level and the diamagnetic coalescence of the energy band levels. For intrinsic absorption processes, the *IMO* effect does not depend on the presence of free carriers and can be carried out under conditions where the free carrier concentration is either too small or too large for cyclotron resonance experiments. The *IMO* effect should be particularly useful for obtaining information about energy bands whose edges occur away from the forbidden energy gap.

Invited Paper

T11. Measurement of Short Semiconductor Lifetimes by Pulsed Van de Graaff Excitation. G. K. WERTHEIM, *Bell Telephone Laboratories.* (30 min.)

SATURDAY MORNING AT 9:30

Mosaic Room

(C. ZENER presiding)

Metals

TA1. Domain Treatment of Order-Disorder Theory.* LOUIS GOLD, *Lincoln Laboratory.*—Conventional theories of order-disorder (as the familiar Bragg-Williams or Bethe approaches) have ignored domains[1] whose existence recently has received considerable confirmation.[2] Clearly the energetics of the system may become considerably altered by the subboundaries. Thus in addition to the usual free-energy minimization with respect to the long-range order parameter w, a separate minimization with respect to a domain size parameter enters. The dependence of w upon T may be expressed in the form $(kT)^2+F_1kT+F_2=0$ where F_1 and F_2 are rather involved functions of the binary composition, the coordination number and binding energies in a volume or surface region and w itself. It emerges then that more than one critical temperature may arise for a given composition—a situation which has no counterpart in extant theories. Calculations now are in progress to characterize domain sizes, free energies, and transition temperatures for typical alloys.

* The research reported in this document was supported jointly by the U. S. Army, Navy, and Air Force under contract with M. I. T.

[1] Sykes and Jones, Proc. Roy. Soc. (London) **A157**, 213 (1936).
[2] A. R. Ubbelohde, Brit. J. Appl. Phys. **7**, 313 (1956).

TA2. Thermal Conductivity in High-Resistivity Alloys. J. E. ZIMMERMAN, *Ford Motor Company.*—Heat conduction measurements at helium temperatures have been made on a number of alloys of widely varying electrical resistivity and the lattice components of the thermal conductivities have been calculated. For low-resistivity specimens, the lattice conductivities K_g have been found to be proportional to T^3, which, according to the thermal conductivity theory developed by Makinson (1938) and by later workers, is to be expected for the case of phonons scattered predominantly by the free electrons. This T^3 behavior has been observed experimentally by a number of workers for various alloys. For the specimens of high electrical resistivity, a large linear term is observed in K_g. This is not explained by the published theory, but agrees fairly closely with a recent theoretical treatment by Pippard (unpublished) of the electron-phonon interaction when the electron mean free path is comparable with the phonon wavelength.

TA3. Scattering of Electrons by Impurities in Metals. LAURA M. ROTH,* *Harvard University* (introduced by Benjamin Lax).—Scattering of electrons by impurities in monovalent metals has been studied by a Green's Function method. For the spherical model, a partial wave analysis resulted including the crystalline potential, as well as the impurity. The method was applied to monovalent impurities, and a generalization of Mott's[1] square well approximation obtained. The residual resistivity of noble metal alloys was computed using Kambe's[2] calculation for the wave functions. Agreement with experimental results is better than in the Mott approximation. A calculation was also made for divalent impurities, representing electronic screening with a constant additional potential inside the impurity cell and a screened Coulomb outside, adjusted so that Friedel's sum rule is obeyed for the total phase shifts. The quantum defect method was used for the impurity potential, and a perturbation method for the outside potential. Results for Zn, Cd, and Hg in Ag and Cu tend to follow experimental values, although they are somewhat high. For Au, agreement is less satisfactory.

* Now at Lincoln Laboratory.
[1] N. F. Mott, Proc. Cambridge Phil. Soc. **32**, 281 (1936).
[2] K. Kambe, Phys. Rev. **99**, 419 (1955).

TA4. Reversible Temperature Effects in the Reflectivity of CsCl-Type Alloys. L. MULDAWER, *Temple University and Ford Motor Company.*—A number of CsCl structure alloys undergo reversible color changes as a function of temperature. β brass turns copper-red at about 250°C, the color changes taking place gradually. β-AgZn is pink at room temperature, it is silver-gray at 250°C. Similar changes have been observed in β-AgCd, β-AuZn, and β-AuCd. Color changes consistent with the above observations have been noted on cooling to liquid nitrogen temperatures. Although disordering takes place in some of these alloys it is not thought that this color change phenomenon is primarily due to disorder or to surface films. Quantitative measurements of reflectivity as a function of wavelength at several temperatures have been made on β brass, β-AuZn, and gold modified β-AgZn and β-AgCd. The reflectivity minimum for β brass at 27°C is at 4750 A, while at 275°C it is at 5000 A. This is a shift of about 5×10^{-4} ev/°C. No such color effects were observed with Cu, Au, Cu_3Au, or α brass. The possible nature of the effect will be discussed.

TA5. Some Thermal Radiation Properties of Metals.* B. D. SCHURIN AND J. C. MORRIS, *Armour Research Foundation.*—The total normal emissivities of nickel, copper, molybdenum, tantalum, and platinum have been measured as a function of temperature in the range −300°F to 3000°F. The measurements were made in the polished and the oxidized states. Preliminary information on the angular distribution of the total radiation has been obtained and deviations from the Lambert cosine law recorded. Values for the total hemispherical emissivities have been calculated. The metals were prepared in the form of thin strips and heated by electrical conduction. Temperatures were measured with Pt-Pt 10% Rd thermocouples imbedded in the samples; the diameter of the thermocouple wires was 0.003 in. The radiation from the samples, chopped at 16 cps, was recorded with a thermistor detector incorporated into a folded optics system. The signal was compared to that from an experimental blackbody at the same temperature and the ratio of the signals taken as the emissivity. The measurements are in qualitative agreement with the relation for hemispherical emissivity derived by Davisson and Weeks.[1]

* Work sponsored by Wright Air Development Center.
[1] C. Davisson and J. R. Weeks, J. Opt. Soc. Am. and Rev. Sci. Instr. **8**, 581 (1924).

TA6. Polarization Effects in the Alkali Metals. JOSEPH CALLAWAY,* *University of Miami.*—An approximate potential is proposed to represent the effect of polarization of the atomic core by the valence electron in the alkali metals. This potential acts on the valence electron and is given by

$$V_P(R) = -2/R^3 \sum_i \int_0^R U_i^*(r) r \cos\theta \phi_i(r) d^3r,$$

where U_i is the unperturbed wave function for core state i and ϕ_i is the perturbed wave function calculated by Sternheimer.[1] First-order perturbation theory was applied to determine the effect of this potential. Expectation values were found for the lowest state of the valence electron in the free atom and to order k^2 for the solid. The energies of the levels are lowered and an increase of the cohesive energy by 8.7 kcal/mole was obtained for potassium. Smaller results were obtained for sodium and lithium.

* Supported by the Office of Naval Research.
[1] R. M. Sternheimer, Phys. Rev. **96**, 951 (1954).

TA7. Friedel Theory of Thermoelectric Power Applied to Magnesium Alloys. E. I. SALKOVITZ, A. I. SCHINDLER, AND E. W. KAMMER, *U. S. Naval Research Laboratory.*—In Friedel's[1] theory of the thermoelectric power of alloys there appears a parameter $\Delta X = -E_F(\partial \log\rho/\partial E)_{E_F}$ where E_F is the Fermi energy and $\Delta\rho$ is the change in resistivity due to alloying. The theory predicts ΔX is a constant independent of alloying. Since measurements of the thermoelectric power and resistivity have already been made on a series of dilute magnesium alloys,[2] the Friedel theory was applied to the data. A plot was made of ΔX *versus* composition. A significant feature of the plot is that the data are separable into groups of curves, each relatively constant with composition. The separation into groups is found to be dependent upon the valence of the impurity atom. This indicates a dependence of ΔX upon the impurity valence, a feature not apparent in the copper alloys discussed by Friedel. In the Friedel theory the Fermi energy is assumed to remain constant as alloying takes place. However the data reported here indicate that this may not be the case for the magnesium alloys.

[1] J. Friedel, J. phys. radium **14**, 56 (1953).
[2] Salkovitz, Schindler, and Kammer (to be published).

TA8. Electrical Resistivity of Thin Films of Potassium.* D. G. WORDEN† AND G. C. DANIELSON, *Iowa State College.*—The electrical resistivity of thin potassium films at 100°K has been measured as a function of thickness in the thickness range 148 to 1600 A. The experimental results are in excellent agreement with Fuchs' theoretical predictions in the range 500 to 1600 A and show that the scattering of the electrons at the film surfaces is completely diffuse. Comparison of experimental and theoretical curves gives a bulk resistivity parameter of 1.85 μohm cm, a mean free path of 1180 A, and an electron to atom density ratio of 1.01. The films were deposited on a Pyrex substrate from a beam of potassium vapor in a vacuum chamber which had a pressure less than 5×10^{-8} mm of Hg. The film thickness, in each case, was computed from a known beam intensity, exposure time, and film density. A surface ionization detector was used to calibrate the beam intensity (J_1) as a function of effusion oven temperature (T_0). The linear plot of $\log(J_1T_0^{\frac{1}{2}})$ *versus* T_0^{-1} gave a heat of sublimation for potassium at 450°K of 21.1 kcal/mole in good agreement with Brewer's value of 21.4 kcal/mole within our experimental error.

* Work was performed in the Ames Laboratory of the U. S. Atomic Energy Commission.
† Present address: G. E. Research Laboratory.

Invited Paper

TA9. Equations of State for Solid and Liquid Metals. G. BORELIUS, *Tekniska Högskola, Stockholm.* (30 min.)

SATURDAY MORNING AT 9:30

Panel Room

(C. E. MANDEVILLE presiding)

Nuclear Reactions and Nuclear-Energy Levels, III

U1. Proton Bombardment of Natural Magnesium. ROBERT T. SMITH, JR., AND DAVID BREITENBECHER, *Wright-Patterson Air Force Base.*—The 2-Mev Van de Graaff generator at this laboratory has been converted for positive ion acceleration and calibrated with the well-known resonances of fluorine at 340.5, 669, 873.5, 935.3, and 1381 kev. An additional calibration point was obtained at the 1.882-Mev threshold for the $Li^7(p,n)Be^7$ reaction. Thin natural magnesium targets evaporated on 0.005 in. tantalum backing have been bombarded by protons in the energy range from 250 kev to 2100 kev. Gamma-ray yield per proton detected by a 2-in. NaI crystal on 6292 photomultiplier tube is plotted as a function of energy. For proton energies up to 1.3 Mev the known resonances[1,2] for all three isotopes were obtained with an additional resonance at $E_p = 623$ kev which appears to be due to Mg^{25} excitation. Above 1.3 Mev new resonances were found for $E_p = 1335$, 1381, 1592, 1647, 1687, 1742, 1760, 1770, 1800, 1845, 1922, 1955, and 2088 kev. Most of the resonances above 1500 kev have a width at half-maximum around 7 to 15 kev and appear to be the result of Mg^{24} excitation.

[1] P. M. Endt and J. O. Kluyver, Revs. Modern Phys. **26**, 95 (1954).
[2] Litherland, Paul, Gove, and Bartholomew, Phys. Rev. **102**, 208 (1956).

U2. Angular Distribution of N^{13} from $Mg^{25}(N^{14},N^{13})Mg^{26}$. M. L. HALBERT AND A. ZUCKER, *Oak Ridge National Laboratory.*—The angular distribution of 10-min N^{13} has been measured at 27.5 Mev by a simple activation technique. The observed N^{13} must have been produced in its ground state because excited states are unstable to particle emission. The distribution of N^{13} from reactions in which the residual Mg^{26} is left with less than ~5 Mev excitation has a peak at about 64° (center-of-mass angle for ground state). At forward angles $d\sigma/d\omega$ is less than $\frac{1}{10}$ of its peak value; the rise begins near 35°. At 80° it has dropped to about half its peak value. If this reaction is considered as Rutherford scattering with an incidental transfer of a neutron, the distance of closest approach of the two nuclei can be calculated for a given angle and incident energy. Expressing this distance as $D_0(14^{\frac{1}{3}}+25^{\frac{1}{3}})\times10^{-13}$ cm, the peak corresponds to $D_0\sim1.9$, and the half-value point on the rise to $D_0\sim2.2$. Most transfers occur when the nuclei are not touching. The drop at large angles presumably results from competition with compound nucleus formation (80° corresponds to $D_0\sim1.6$). Roughly 25% of the transfers leave Mg^{26} excited more than 5 Mev, and N^{13} from these is peaked at larger angles.

U3. Nitrogen-Induced Neutron Transfer Reactions in Be, C, O, Na, Mg^{24}, Mg^{25}, Mg^{26}. A. ZUCKER, M. L. HALBERT, T. H. HANDLEY, J. J. PINAJIAN, AND W. H. WEBB, *Oak Ridge National Laboratory.*—Excitation functions were measured for the production of 10.1-min N^{13} from the bombardment of Be^9, C^{13}, O^{16}, Na^{23}, Mg^{24}, Mg^{25}, and Mg^{26} by energetic nitrogen ions. The incident energy was varied from 16 to 28 Mev by placing nickel absorbers in the beam. N^{13} was chemically separated from the targets and thick target yields were established by absolute beta counting. It was found that the cross sections for the transfer of a neutron from the nitrogen to the target nucleus are strongly Q dependent. For example, at the maximum beam energy the transfer cross section for Mg^{26} is 2.8 mb, while for O^{16} at the same energy the cross section is 0.12 mb.

If the cross sections are plotted as a function of $E^* = E_{cm} - E_{barr} + Q$ a uniform behavior becomes apparent for most of the transfer cross sections. The cross sections for transfer reaction drop less steeply below $E^* = 0$ than the cross sections for reactions in which a few particles are emitted from a compound nucleus. Above $E^* = 0$ the transfer reaction cross sections seem to level off at about 3 mb, while the evaporation cross sections rise to a few hundred millibarns.

U4. Inelastic Proton Scattering from Phosphorus and Zinc.* D. M. VAN PATTER, M. A. ROTHMAN, W. C. PORTER, AND C. E. MANDEVILLE, *Bartol Research Foundation.*—Inelastic proton spectra from targets containing phosphorus and zinc have been studied at bombarding energies of 3.72 and 4.66 Mev using a double-focusing magnetic spectrometer. Proton groups have been observed corresponding to levels in P^{31} at 1.264 ± 0.004, 2.231 ± 0.006, 3.136 ± 0.008, and 3.295 ± 0.006 Mev, in excellent agreement with the independent measurements of Endt *et al.*[1] Excitation curves for these four inelastic proton groups measured in the region of $Ep = 4.55$ to 4.70 Mev show the same general resonant structure, although differing in detail. At $Ep = 4.66$ Mev, no additional groups from P^{31} were observed for the excitation region 0–1.26 Mev with an intensity greater than 2% of the intensity of the first excited state group. Four inelastic proton groups were observed from zinc. From a comparison with the known level schemes of the zinc isotopes, three of these groups were assigned to the following isotopes: Zn^{66} 0.991 ± 0.005 Mev; Zn^{68} 1.038 ± 0.005 Mev; and Zn^{68} 1.078 ± 0.005 Mev. The remaining group with $Q = -1.802 \pm 0.007$ Mev remains unassigned.

* This research was supported by the U. S. Air Force, through the Office of Scientific Research of the Air Research and Development Command.
[1] P. M. Endt *et al.* (private communication).

U5. Reactions of Alpha Particles with Fe^{54}.* J. M. MILLER AND F. S. HOUCK, *Columbia University and Brookhaven National Laboratory.*—Excitation functions have been determined for the (α,n), (α,p), $(\alpha,2n)$, (α,pn), $(\alpha,p2n)$, and $(\alpha,2pn)$ reactions between Fe^{54} and alpha particles ranging in energy from 5 to 40 Mev. It was found that the (α,p) cross section was approximately three times that of the (α,n) reaction for incident energies exceeding the (α,n) threshold by a few Mev; while for energies exceeding the $(\alpha,2n)$ threshold by a few Mev the (α,pn) cross section was about sixty times that of the $(\alpha,2n)$ reaction. Evidently, processes in which the proton is the second particle emitted make a major contribution to the (α,pn) reaction with Fe^{54}. That an intermediate nucleus in this reaction, Ni^{57}, should favor proton emission is probably a consequence of the doubly magic, $T_z = 0$, character of Ni^{56}, the product of the competing neutron emission from Ni^{57}. From an analysis of the relative probabilities for one and two particle evaporation from the compound nucleus, Ni^{58}, a value of 1.1 was found for "a," the level density parameter.[1]

* Work supported in part by the U. S. Atomic Energy Commission.
[1] J. Blatt and V. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 371.

U6. Lifetimes of the First Excited States of Ca^{40} and Zr^{90}.* R. M. KLOEPPER, R. B. DAY, AND D. A. LIND, *Los Alamos Scientific Laboratory.*—The first excited states of Ca^{40} and Zr^{90} are 0^+ states which decay to the 0^+ ground states principally by the emission of internal pairs or conversion electrons. In the work reported here these states have been excited by neutron inelastic scattering and their decay times have been observed by detecting the 0.51-Mev gamma rays resulting from the annihilation of the positrons. The experimental method utilized a pulsed neutron source and the standard ring geometry often used for inelastic scattering measurements. Because of the large background present it was necessary to measure the pulse-height spectrum from the NaI(Tl) scintillation counter as a function of delay time after the neutron pulse and to obtain the intensity of the annihilation radiation from the area under the 0.51-Mev photopeak. Fast time measurements were made with the aid of a time-to-pulse-height converter. Successive portions of the converted time spectrum were selected by a single-channel analyzer whose output gated the 100-channel analyzer used to obtain the pulse-height distributions. Preliminary results, which are subject to later corrections, give half-lives for the first excited states of Ca^{40} and Zr^{90} of 1.4×10^{-9} sec and 5×10^{-8} sec, respectively. A comparison of these lifetimes with theoretical expectations will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

U7. Compound States Formed in the Reactions $Fe^{54}(p,p'\gamma)$ and $Ti^{46}(p,p'\gamma)$.* F. W. PROSSER, JR., C. M. CLASS, R. H. DAVIS, J. H. JOHNSON, AND J. P. SCHIFFER,† *The Rice Institute.*—The excitation curves for inelastic scattering to the 2^+ first excited states in Fe^{54} and Ti^{46} have been determined for proton bombarding energies between 2.5 and 5.0 Mev. This has been done by measuring the yield of the well-resolved γ rays of 1.41 Mev from Fe^{54} and 0.89 Mev from Ti^{46}. The bombarding energies used correspond to mean excitation energies in the compound nuclei of 9 and 8 Mev, respectively. By using an isotopically enriched target 2 kev thick, approximately 130 resonances were located in Fe^{54} of which about 70 were sufficiently intense to permit the measurement of the γ-ray angular distribution. In Ti^{46}, 90 intense resonances were studied in a similar way. In the majority of these cases the distributions of the γ radiation are consistent with spin assignment of 3/2 or 5/2 to the compound states, formed by d-wave and decaying by s-wave protons. The absolute yield of these states was measured in order to obtain the integrated cross section.

* Supported in part by the U. S. Atomic Energy Commission.
† Now at the Argonne National Laboratory.

U8. Level Parameters of the Compound States Derived from the $Fe^{54}(p,p'\gamma)$ and $Ti^{46}(p,p'\gamma)$ Reactions.* R. H. DAVIS, F. W. PROSSER, JR., AND C. M. CLASS, *The Rice Institute.*—The inelastic scattering of low-energy protons from the 2^+ first excited states of even-even nuclei in the mass range $40 < A < 60$ occurs preferentially by way of compound states with spins $5/2^+$ or $3/2^+$ with $l = 0$ for the emitted protons. In Fe^{54} and Ti^{46} about 150 such states have been observed, and in Ni^{58} about 35 more have been reported.[1] From the measured integrated cross sections for these states, s-wave reduced widths can be derived which are accurate to about a factor of two apart from a systematic uncertainty in the penetrabilities. From the reduced widths and the observed level spacings, the strength functions $\langle\gamma^2\rangle/\bar{D}$, which the optical model predicts to show a maximum in this region of A for s-wave neutrons, have been calculated. The distribution of reduced widths also has been determined and agrees qualitatively with that found in the neutron measurements. Experimental evidence suggests that both the level spacings and the reduced widths are spin dependent.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Shiffer, Moore, and Class, Phys. Rev. **104**, 1661 (1956).

U9. Measurements of $\bar{\gamma}^2/\bar{D}$ for Inelastic Proton Scattering Using Thick Targets.* J. P. SCHIFFER, *The Rice Institute and Argonne National Laboratory,* AND R. H. DAVIS AND F. W. PROSSER, JR., *The Rice Institute.*—The thick target yields for inelastic scattering of protons on even-even nuclei can be used, under certain conditions, as a measure of the strength function, $\bar{\gamma}^2/\bar{D}$, for the channel of s-wave inelastic protons from the compound nucleus. The principal conditions are that the inelastic proton energy be sufficiently small compared to the Coulomb barrier to inhibit other l values and that the inelastic scattering should occur from a 0^+ ground state to a 2^+ excited

state. It appears from measurements on seven isotopes, between $A=46$ and 60, that $\bar{\gamma}^2/\bar{D}$ is constant within 50%. This may be compared with the resonance in $\Gamma_n^0/\bar{D}$ found in neutron scattering experiments on nuclei in this region.

* Supported in part by the U. S. Atomic Energy Commission.

U10. Coulomb Excitation of Levels in Fe^{57}. N. P. Heydenburg and G. F. Pieper, *DTM, Carnegie Institution of Washington.*—Gamma rays of energies 350, 230, and 123 kev have been observed from Coulomb excitation by alpha bombardment of an enriched Fe^{57} target. Using $Fe^{56}(d,p)Fe^{57}$, Sperduto and Buechner[1] observed levels in Fe^{57} at 14, 137, and 365 kev. We assign the 350-kev and 230-kev gamma rays to cascade transitions from the 365 to the 14 and 137 levels, respectively. Thick target excitation curves show that the 123-kev gamma ray is primarily the result of Coulomb excitation of the 137 level and that the 350-kev and 230-kev gamma rays are the result of Coulomb excitation of the 365 level. The branching ratio of the 350-kev and 230-kev transitions was observed to be 13:1. No transition between the 365 level and the spin $1/2^-$ ground state was observed; if such a transition exists, its intensity is less than 5% of the 350-kev radiation. On the basis of these observations, we tentatively assign spin $5/2^-$ to the 365 level. Coincidence measurements between cascading gamma rays are in progress.

[1] A. Sperduto and W. W. Buechner, Bull. Am. Phys. Soc. Ser. II, 1, 223 (1956).

U11. Excited States of Ni^{58} and Ni^{60}.* C. H. Paris and W. W. Buechner, *M. I. T.*—Thin natural nickel targets and NiO targets enriched in Ni^{58} have been bombarded with 7.0-Mev and 6.5-Mev protons from the MIT-ONR generator. The emerging protons have been analyzed at 30, 90, and 130 degrees with the broad-range spectrograph. Inelastically scattered proton groups, corresponding to levels in Ni^{58} were observed at 1.451 ± 0.007; 2.458 ± 0.007; 2.773 ± 0.007; 2.900 ± 0.006; (2.939 ± 0.006); 3.035 ± 0.006; 3.260 ± 0.006; and 3.418 ± 0.005 Mev. From comparison of the proton groups resulting from the bombardments of the natural nickel target and the target enriched in Ni^{58}, the following levels are assigned to Ni^{60}: 1.332 ± 0.010; 2.158 ± 0.010; 2.285 ± 0.010; 2.505 ± 0.010; 2.627 ± 0.010; 3.119 ± 0.010; 3.185 ± 0.010; 3.192 ± 0.010; 3.316 ± 0.010; and 3.391 ± 0.010 Mev. A level at (1.172 ± 0.010) Mev is tentatively assigned to Ni^{60}.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

U12. Study of $Cu^{65}(p,n)Zn^{65*}$ Reaction by Conversion Electrons.* E. M. Bernstein and H. W. Lewis, *Duke University.*—A study has been made of the prompt internal conversion electrons from low-energy transitions in Zn^{65} excited by the $Cu^{65}(p,n)Zn^{65*}$ reaction. The electron spectrum from a thin Cu foil bombarded with 3 to 4 Mev protons was analyzed with a magnetic β-ray spectrometer. Previous investigation[1] of the neutrons from this reaction at 3 Mev bombarding energy showed the existence of a neutron group corresponding to a level at 118 kev and of intensity approximately equal to that of the ground state. Transitions of 52, 92, and 114 kev have been reported[2] in the positron decay of Ga^{65}. In the present experiment the following transitions in Zn^{65} have been observed (the K to $L+M$ ratios, where measured, are given following the transition energy in kev); 54 ± 3; 88 ± 3; 119 ± 3, 8.5; 155 ± 3, 7.2; 209 ± 4. Evidence is also found for a transition of 65 ± 3 kev. Interpretation of the data gives levels in Zn^{65} at 54 ± 3, 119 ± 3, and 209 ± 4 kev with the levels at 119 and 209 kev being directly excited by the p-n reaction.

* Supported by the U. S. Atomic Energy Commission.
[1] J. B. Marion and R. A. Chapman, Phys. Rev. **101**, 283 (1956).
[2] B. Crasemann, Phys. Rev. **93**, 1034 (1954).

Saturday Morning at 9:30

Boston-Washington Room

(G. Chew presiding)

Theoretical Physics, V: High-Energy Scattering

UA1. Properties of the Fixed Source Meson Theory.* Katsumi Tanaka, *Argonne National Laboratory.*—The renormalized p-wave coupling constant f^2 is determined from experiments. We solve a set of equations proposed by Ekstein[1] which are essentially of the type $\langle\Psi_\beta,[H,A]\Psi_0\rangle=0$ to compute the ratio $\rho_1(\rho_2)$ of the matrix elements of the operator $\tau(\sigma\tau)$ between physical nucleon states and those between bare states. H is the total Hamiltonian given by Chew and Low and A is a normal product of creation destruction operators and $\sigma\tau$ operators. The ratios are expressed in terms of f^2 and a cutoff Ω. A sum rule in terms of an integral over the phase shift δ_{33}, $\rho_1\rho_2$, and f^2 is obtained from relations given by Cini and Fubini.[2] Finally substituting ρ_1 and ρ_2 into the sum rule we find $f^2=0.09$ for $\Omega=5\,\mu$. We then calculate the expectation value of the number, charge, and energy of the meson cloud of the nucleon in terms of f^2 and Ω without making use of the experimental data.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. Ekstein, Nuovo cimento (to be published).
[2] M. Cini and S. Fubini, Nuovo cimento **3**, 764 (1956).

UA2. On the Soluble Model of s State Meson-Nucleon Scattering.* E. Lomon, *Cornell University.*—The s state meson-nucleon scattering phase shifts have been obtained as exact solutions of a Hamiltonian which may plausibly represent the main s state contribution of the $ps(ps)$ Hamiltonian in a non-relativistic approximation.[1] The phase shift solutions will be discussed as a function of the parameters (two coupling constants and a cutoff). It will appear that for allowable values of the parameters, the isotopic spin $\frac{1}{2}$ state must change sign for $k/\mu<2.3$. The commutation rules of the "double operators" will be discussed to clarify the derivation of reference 1. In addition the formalism for the treatment of inelastic scattering will be developed. The probability amplitude for any odd number n of nucleons to come out of the reaction is obtainable exactly by determining the wave function Ψ that satisfies $(\bar{P}_k P_k+\omega_k{}^3\bar{Q}_k Q_k)\Psi=\omega_k\Psi$ up to an approximation that includes $\leq n$ real outgoing mesons. $\bar{P}_k$, P_k, $\bar{Q}_k$, and Q_k are the "double operators" which diagonalize the Hamiltonian.

* Supported in part by joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] E. Lomon, Nuovo cimento **4**, 106 (1956).

UA3. Dispersion Relations for Fixed Source Meson Theories. R. E. Norton and Abraham Klein, *University of Pennsylvania.*—Dispersion relations have been constructed

for all transition processes of a scalar meson field $\phi(\mathbf{x})$ coupled to a fixed extended source $\rho(\mathbf{x})$ by means of the interaction

$$H' = \sum_{i=1}^{N} \lambda_i \left(\int \rho(\mathbf{x}) \phi(\mathbf{x}) d^3\mathbf{x} \right)^i,$$

involving N terms, the ith term describing an i-fold vertex. The relations were obtained for the ratio of the general transition amplitude to a suitable product of the Fourier transforms of the source functions, since this ratio has a known dependence on the total energy of the system. The salient characteristics of the resulting system of equations are that they involve in all only N arbitrary constants, but that their use for multiple boson processes requires knowledge of the imaginary part of the amplitudes for energies below the physical thresholds. We are studying the question of the completeness of the relations, i.e., the sense in which they exhaust the content of the theory.

UA4. Isobaric Nucleon Model for Pion Production in Nucleon-Nucleon Collisions.* R. M. STERNHEIMER AND S. J. LINDENBAUM, *Brookhaven National Laboratory.*—A detailed quantitative model for pion production in nucleon-nucleon collisions via excitation of one or both nucleons to an isobaric state, with subsequent decay by pion emission, is presented. The model is used in the range of incident nucleon energies from 0.8 to 3.0 Bev and its predictions are compared with various experiments in this energy range performed at the Brookhaven Cosmotron. The isobaric state with isotopic spin and angular momentum $=\frac{3}{2}$ observed in the pion-nucleon scattering was assumed to be predominantly responsible for pion production in this energy range. The relative probability for producing isobars of different mass (=total energy in isobar rest system) was phenomenologically related to the $\pi^+ + p$ total scattering cross section and to the phase space available for the isobar. The energy spectra of pions and recoil nucleons, the variation of the ratio of double to single production, the angular correlations and Q-value distributions for pion-nucleon pairs have been calculated at various energies from 0.8 to 3.0 Bev. These results are in reasonable agreement with the experimental data.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

UA5. Pion Production in Pion-Nucleon Collisions.* L. S. RODBERG,† *M.I.T.*—The T matrix describing the production of p-wave pions in pion-nucleon collisions has been investigated using the Chew-Low[1] formalism. Methods analogous to those of reference 1 were used, and an approximate solution was obtained including one-meson intermediate states. This solution satisfies an approximate form of the unitarity requirement.‡ Numerical evaluation of the production cross sections, using extrapolations of the known low-energy scattering data, shows a peak for incident meson kinetic energies of about 700 Mev. The magnitudes of the production cross sections are uncertain since the scattering phase shifts for high energies are not known. Estimates give production cross sections of about 1 mb. The solutions have been used to obtain the two-meson corrections to the Chew-Low equation for the scattering amplitude. These are found to be quite small.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† National Science Foundation Predoctoral Fellow, 1954–1956.
[1] G. F. Chew and F. E. Low, Phys. Rev. **101**, 1570 (1956).
‡ The production amplitude is expressed in terms of scattering amplitudes describing the two outgoing mesons and the incoming meson; thus knowledge of the high-energy scattering phase shifts is required.

UA6. Radiative Meson Scattering. R. E. CUTKOSKY, *Carnegie Institute of Technology.*—The static source model of the pion-nucleon interaction has been used to calculate the bremsstrahlung emitted in pion-proton scattering. Application of the methods of Chew and Low[1] and Wick[2] enables one to express the matrix element for radiative meson scattering in terms of the scattering phase shifts and other experimentally determined quantities provided the static source movel is valid. Comparison of experimental results with those calculated using this simple model will, therefore, suggest the refinements which are needed. In the numerical calculations, certain corrections for nucleon recoil and S-wave scattering were incorporated in a semiphenomenological way by comparing with the semiclassical result; other corrections which are not unambiguous were left out. Gamma-ray spectra at several angles were calculated for the scattering of positive pions by protons at laboratory energies of 130 Mev, 175 Mev, and 220 Mev. The total cross sections for emission of gamma rays with energies (in the c.m. system) greater than 30 Mev are calculated to be 0.17 mb at 130 Mev, 0.42 mb at 175 Mev, and 0.59 mb at 220 Mev.

[1] G. F. Chew and F. Low, Phys. Rev. **101**, 1570, 1579 (1956).
[2] G. C. Wick, Revs. Modern Phys. **27**, 339 (1955).

UA7. Photodisintegration of He^4.* M. L. RUSTGI AND J. S. LEVINGER, *Louisiana State University.*—We apply sum rules[1] to calculate the electric dipole bremsstrahlung-weighted cross section σ_b and the integrated cross section σ_{int}, using Irving's[3] helium wave function for tensor forces. We compare our results with values found from the experiments of de Saussure and Osborne,[3] Smith and Barton,[4] and others,[2] integrated to 150 Mev. The experimental values are $\sigma_b = 2.5$ mb and $\sigma_{\text{int}} = 120$ Mev-mb; while the theoretical values are $\sigma_b = 1.25$ mb and $\sigma_{\text{int}} = 60\ (1 + 0.70x + 0.18x')$ Mev-mb. Here x and x' are the fractions of central and tensor potentials, respectively, that have the Majorana exchange character. The low theoretical value for σ_b may be related to the small root-mean-square radius of the alpha particle[5] given by Irving's wave function.

* Supported by the Research Corporation.
[1] J. S. Levinger, Phys. Rev. **97**, 122 (1955).
[3] J. Irving, Proc. Phys. Soc. (London) **A66**, 17 (1953).
[3] G. de Saussure and L. S. Osborne, Phys. Rev. **99**, 843 (1955).
[4] J. S. Smith and M. Q. Barton, Phys. Rev. **100**, 1265(A) (1955), and private communication.
[5] R. Hofstadter, Revs. Modern Phys. **28**, 214 (1956).

UA8. Some Aspects of the Structure of Nucleons as Deduced from Electron Scattering Experiments. B. T. FELD, *M.I.T.*—Experiments on the scattering of electrons by protons yield the value $\langle r^2 \rangle_P^{\frac{1}{2}} \cong 0.8$ fermi for the spread of the charge cloud associated with the proton.[1] Neutron-electron scattering indicates, for the neutron charge distribution, $\langle r^2 \rangle_N^{\frac{1}{2}} < 0.2$ fermi. These charge spreads cannot arise solely from the pion clouds in the nucleons since charge independence requires that these be identical, except for a reversal of sign, in the neutron and proton. The asymmetry introduced by the hyperon, K-meson interaction[2] may be shown to be insufficiently large to account for the difference. Thus, short of a breakdown of electrodynamics, one is forced to the conclusion that the nucleon "core" has a spacial extent of the same order as the pion cloud. A simple model of the nucleon, which embodies these properties as well as other known aspects of the meson-nucleon interaction, will be presented and discussed.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] R. Hofstadter, Revs. Modern Phys. **28**, 214 (1956).
[2] G. Sandri, Phys. Rev. **101**, 1616 (1956).

UA9. Proton Polarization Correction to Electron-Proton Scattering. S. D. DRELL, *Stanford University,* AND M. A. RUDERMAN, *University of California, Berkeley.*—In analyses of the scattering of high-energy electrons by protons[1] the electric-charge and magnetic-moment distributions of the proton have been treated as if rigid. This ignores effects on the scattering

due to the electron-induced polarization of this charge and current cloud. This polarization is responsible for the nuclear Compton effect. Although it contributes only e^3 corrections to the main term of the electron-proton scattering amplitude, the proton polarizability can be anomalously large near those frequencies for which photomeson production is big, i.e., $\hbar\omega$ from 200 to 400 Mev. These are also the significant electromagnetic-field frequencies felt by the proton in small impact parameter, large-angle electron scatterings which are sensitive to the charge and current distribution of the proton. In this work the polarization contribution to the observed scattering is evaluated. For electrons scattered through 90° it is found to be $\gtrsim \frac{1}{2}\%$ at 400 Mev and an increasing function of energy.

[1] E. E. Chambers and R. Hofstadter, Phys. Rev. **103**, 1454 (1956).

UA10. Nuclear Cascades. I. Mechanics and Low Energy Studies. R. Bivins, N. Metropolis, and M. Storm,* *Los Alamos Scientific Laboratory*, A. Turkevich, *University of Chicago*, J. M. Miller, *Columbia University*, and G. Friedlander, *Brookhaven National Laboratory*.—Nuclear cascade calculations have been carried out at the MANIAC electronic computer. Previous Monte Carlo calculations of this type[1] have been extended into the Bev region as well as improved statistically at lower energies. A three-dimensional geometry was used, and nucleons and charged and neutral pions followed. Except in absorption processes the particles were assumed to interact with individual nucleons inside the nucleus according to observed free scattering cross sections. The absorption of pions was assumed to take place via a two nucleon process.[2] The single and double production of mesons was taken as isotropic with equal sharing of momenta among the particles involved in the center of mass of the collision. The number, kind, energy, and direction of the emitted particles in each cascade and the nature and state of excitation of the residual nucleus were tabulated and then analyzed statistically. A typical study involved about 10^3 incident particles. The target nuclei investigated were Al, Cu, Ru, Ce, Bi, and U. Some comparison of the low-energy cascades with experiments and a few summaries will be presented.

* Now with Midwestern Universities Research Association (MURA), Madison, Wisconsin.
[1] M. L. Goldberger, Phys. Rev. **74**, 1268 (1948); Bernardini, Booth, and Lindenbaum, Phys. Rev. **88**, 1017 (1952); McManus, Sharp, and Gellman, Phys. Rev. **93**, 924(A) (1954); J. W. Meadows, Phys. Rev. **98**, 744 (1955).
[2] E.g., N. C. Francis and K. M. Watson, A. J. Phys. **21**, 659 (1953).

UA11. Nuclear Cascades. II. High-Energy Results.* G. Friedlander and J. M. Miller, *Brookhaven National Laboratory and Columbia University*, N. Metropolis, R. Bivins, and M. Storm, *Los Alamos Scientific Laboratory*, and A. Turkevich, *University of Chicago*.—The results of the Monte Carlo calculation of high-energy intranuclear cascades described in the previous abstract have been examined in the energy region in which meson processes are significant. The calculation predicts that the average number of cascade nucleons emitted per inelastic event is remarkably independent of target element (Al to U), but increases with increasing incident energy from about 3 at 400 Mev to about 8 at 2 Bev. Pion production per nuclear interaction is approximately the same for all targets at a given proton energy and increases by roughly an order of magnitude when the energy goes from 0.45 to 2.0 Bev. Excitation energies of residual nuclei increase sharply with increasing incident energy and with increasing mass of target nucleus. The results of the calculations will be compared with radio-chemical data for the case of 2-Bev proton bombardment of copper[1] and with pion multiplicities, energy spectra, and angular distributions observed in emulsion exposures to a 500-Mev π^- beam.[2]

* Work supported by the U. S. Atomic Energy Commission.
[1] Friedlander, Miller, Wolfgang, Hudis, and Baker, Phys. Rev. **94**, 727 (1954).
[2] M. Blau and M. Caulton, Phys. Rev. **96**, 150 (1954).

Saturday Morning at 10:00

North Ballroom

(M. Zemansky presiding)

Cryogenics

V1. Carbon Resistance Thermometry below 1°K.* J. Nicol and T. Soller, *Amherst College*.—In an effort to obtain a predictable and reproducible secondary thermometer for use with cascade adiabatic demagnetization techniques[1] the temperature variation of resistance of sixteen different commercial carbon resistors has been examined between 0.1°K and 4.2°K. The resistors were calibrated between 4.2°K and 1°K and the observed resistance values below 1°K compared with the predictions of the calibration equation. Agreement with an equation of the form[2] $T = A \log R(\log R - B)^{-2}$ was obtained for two groups of resistors distinguished by significantly different values of A and B. For one group $R = 900$ ohms at 4.2°K and 6500 ohms at 0.3°K for a nominal 470 ohms resistor, corresponding to $A = 0.1$ and $B = 2.69$. These compare with $A = 1.67$ and $B = 1.0$ for the other group[3] in which a nominal 10-ohms resistor exceeds 10 megohms at 0.3°K. The lower resistance values at temperatures below 1°K with adequate temperature sensitivity suggest that the 470-ohms resistor will be useful as a thermometer below 1°K.

* Work supported by National Science Foundation and Office of Naval Research.
[1] J. Nicol, Proceedings of the Baton Rouge Conference on Low Temperature Physics and Chemistry (1955), p. 39.
[2] J. R. Clement, quoted by Pearce *et al.*, Rev. Sci. Instr. **27**, 240 (1956).
[3] Clement, Quinnell, Steele, Hein, and Dolecek, Rev. Sci. Instr. **24**, 545 (1953).

V2. Nuclear Spin Coupling in Solid He^3.* H. Primakoff, *Washington University*.—A theoretical description has been attempted of cooperative nuclear magnetic effects in solid He^3. It is predicted that the nuclear spins in solid He^3 are aligned antiparallel with a transition temperature that decreases with increasing pressure ($\approx \frac{1}{2}$°K at ≈ 30 atmos; $\approx 10^{-3}$°K at $\approx 10^3$ atmos). Thus the entropy, at sufficiently low temperatures, increases with increasing pressure so that solid He^3 will have a negative thermal expansion coefficient,

and, will be cooled by adiabatic compression. The "antiferromagnetic" tendency in solid He^3 arises mainly from the dependence of the kinetic energy of the barrier tunneling motion on the "degree" of space symmetry and so the "degree" of spin antisymmetry of the wave function of all the atoms. The barrier tunneling—itself important because of the large zero point vibrations—is that associated with He^3 atoms passing from one lattice cell to another.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

V3. Viscosity of Liquid He^3 and of Liquid He^4.* R. Dean Taylor and J. G. Dash, *Los Alamos Scientific Laboratory.*—Oscillating disk studies have yielded new measurements of the viscosity of liquid He^3 from 1.3°K to the critical point and of liquid He^4 from 1.25° to 4°K. Detailed study of He^4 in the neighborhood of the lambda point shows that the viscosity is continuous through the He I – He II transition, but that its temperature derivative is discontinuous. Viscosity values in He I ($27.8\mu P$ at 2.1735°, $37.3\mu P$ at 2.6°, and $36.0\mu P$ at 4.0°K) show a similar temperature dependence to that reported by other investigators. In He II viscosity values ($24.5\mu P$ at 2.160°, $16.0\mu P$ at 2.0°, $16.5\mu P$ at 1.5°, and $23.9\mu P$ at 1.3°K) confirm published viscometer results of Heikkila and Hallet[1] down to 1.5°K but are progressively higher at lower temperatures. The temperature derivative of the kinematic viscosity η/ρ_n shows no detectable discontinuity at T_λ indicating that the large slope discontinuities in η and ρ_n are of the same magnitude. The viscosity of He^3 rises from $18.7\mu P$ at 3.35° to $26.8\mu P$ at 1.3°K, varying as $T^{-0.35}$ over the entire range.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] W. J. Heikkila and A. C. Hollis Hallet, Can. J. Phys. **33**, 420 (1955).

V4. Specific Heat of Liquid He^4 between 0.4 and 1.5°K.* A. H. Markham, D. C. Pearce,† R. G. Netzel, and J. R. Dillinger, *University of Wisconsin.*—The specific heat of liquid He^4 under its saturated vapor pressure has been measured using two different calorimeters. Between 0.4 and 1.0°K an open-capsule calorimeter was used with arrangements for putting different amounts of helium in with the paramagnetic salt. Thus, the heat capacity of the salt and calorimeter could be subtracted out. Between 0.75 and 1.5°K a calorimeter was used in which the sample holder contained only liquid helium, the heater, and carbon resistor thermometer. Therefore, no salt or vapor corrections were necessary. Below 0.65°K the specific heat could be represented by $2.22\times10^{-3}T^3$ joules g^{-1} deg^{-1}. The constant is approximately 6% smaller than reported by Kramers,[1] and within experimental error agrees with theoretical predictions based on published first sound velocities.[2] We found lower values below 1°K and higher values above 1.1°K than those reported by Kramers. Above 1.1°K our values are in fair agreement with those of Hercus and Wilks.[3] Possibilities of accounting for discrepancies among various sets of data on the basis of different surface-to-volume ratios characteristic of the calorimeters used will be discussed.

* This work was supported in part by the Wisconsin Alumni Research Foundation and in part by the U. S. Atomic Energy Commission.
† Now with the National Research Council of Canada at Ottawa.
[1] Kramers, Wasscher, and Gorter, Physica **18**, 329 (1952).
[2] K. R. Atkins and C. E. Chase, Proc. Phys. Soc. (London) **A64**, 826 (1951).
[3] G. R. Hereus and J. Wilks, Phil. Mag. **45**, 1163 (1954).

V5. Thermal Conductivity of Liquid Helium-3.* D. M. Lee, R. J. Donnelly, and Henry A. Fairbank, *Yale University.*—The transport of heat in liquid He^3 has been investigated and no evidence of superfluidity was observed down to 0.3°K, the heat flux being proportional to the temperature gradient. The thermal conductivity increased from a value of 0.7×10^{-4} watt/cm °K at 0.3°K to 1.9×10^{-4} watt/cm °K at 2.7°K. This behavior is similar to that of He^4 above the λ point[1] and in fair agreement with the classical kinetic theory expression $K=2.5C_v\eta$. The method of measurement closely resembles that used by Fairbank and Wilks for liquid He^4.[2]

* Assisted by the Office of Ordnance Research and the Research Corporation.
[1] C. Grenier, Phys. Rev. **83**, 598 (1951).
[2] H. A. Fairbank and J. Wilks, Proc. Roy. Soc. (London) **A231**, 545 (1954).

V6. (Abstract withdrawn.)

V7. (Abstract withdrawn.)

V8. Chemical Equilibrium Approach to Superconductivity. M. R. Schafroth, S. T. Butler, and J. M. Blatt, *University of Sydney, Australia.*—A charged ideal Bose-Einstein gas is a superconductor below its transition point. In a metal, electrons can pair up to form effective Bose particles. Since these pairs are not bound states, the usual theory of chemical equilibrium is not applicable. In our extension of this theory, the fundamental quantity is not the Hamiltonian of the molecule and its eigenstates, but rather the pair correlation operator and its eigenstates. Unlike the Hamiltonian operator of the pair, the pair correlation operator has only discrete eigenstates, and the distinction between bound and unbound states of the molecule disappears from the theory. By including dynamical correlations only up to pair correlations, but including correlations due to the exclusion principle to infinite order, the many-body problem reduces approximately to an equivalent two-body problem. This latter problem has not been solved yet, but reasonable assumptions about its solution yield a thermodynamic transition to a state obeying the London equation. The approximation is similar to the "linked cluster expansion" of Brueckner; its validity depends upon the "quenching" effect of the exclusion principle. Additional conditions for validity are violated for ordinary interactions between electrons, but may be satisfied for the Froehlich interaction.

SATURDAY MORNING AT 9:30

Grand Ballroom

(E. P. WIGNER presiding)

Symposium on Nuclear Alignment

VA1. Nuclear Orientation and Nuclear Cooling. N. KURTI, *Oxford University.* (30 min.)

VA2. Attempts to Align Nuclei in Doped Silicon Crystals. F. M. PIPKIN, *Harvard University.* (30 min.)

VA3. Nuclear Orientation Experiments at the National Bureau of Standards. E. AMBLER, *National Bureau of Standards.* (30 min.)

VA4. Angular Distribution of Alpha Particles Emitted by Aligned U-233 Nuclei. L. D. ROBERTS, *Oak Ridge National Laboratory.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Grand Ballroom

(L. D. ROBERTS presiding)

Invited Papers on Nuclear Spins and Moments

W1. Advances in the Measurements of the Spins of Radioactive Isotopes. W. A. NIERENBERG, *University of California, Berkeley.* (30 min.)

W2. Paramagnetic Resonant Experiments with Radioactive Nuclei. C. D. JEFFRIES, *University of California, Berkeley.* (30 min.)

W3. Spectroscopy of Ionized Helium 3 in a Metastable State. R. NOVICK, *Columbia University.* (30 min.)

W4. Paramagnetic Resonance in the Astinide Group. B. BLEANEY, *Oxford University.* (30 min.)

SATURDAY AFTERNOON AT 2:00

Terrace Room

(W. H. BRATTAIN presiding)

Semiconductors, II

WA1. Relaxation Time Anisotropy in *n* Germanium. COLEMAN GOLDBERG, *Westinghouse Research Laboratories.*—The anisotropy parameter[1] $w=\tau_{\parallel}m_{\perp}^{*}/\tau_{\perp}m_{\parallel}^{*}$ for *n* germanium can be obtained by calculating magnetoconductance from Hall coefficient and magnetoresistance measurements.[2] This parameter can, however, be obtained more accurately by direct measurement of magnetoconductance. Magnetoconductance can be measured directly if a sample geometry is used which maintains the electric *field* in a fixed direction independent of the magnetic field. (Magnetoresistance measurements use a sample geometry which maintains the electric *current* in a fixed direction.) Magnetoconductance has been measured directly in samples of *n* germanium of varying purity from 45°K to 300°K. For the purest samples w is approximately constant above about 120°K and has the value of about 0.051. If the temperature is lowered below 120°K or if samples of lower purity are used, w increases. Cyclotron resonance measurements[3] give $m_{\perp}^{*}/m_{\parallel}^{*}=0.0518\pm0.0019$ so these magnetoconductance measurements indicate that $\tau_{\parallel}/\tau_{\perp}=1.0$ for lattice scattering, i.e., the relaxation time is isotropic on an energy surface, and the presence of impurity scattering causes the relaxation time to be anisotropic with $\tau_{\parallel}/\tau_{\perp}>1$.

[1] C. Herring and E. Vogt, Phys. Rev. **101**, 958 (1956).
[2] C. Goldberg and R. E. Davis, Phys. Rev. **102**, 1254 (1956).
[3] Dresselhaus, Kip, and Kittel, Phys. Rev. **98**, 368 (1955).

WA2. Defect Dependent Lifetimes in Junction Devices. B. ROSS AND J. R. MADIGAN, *Hoffman Electronics Corporation.*—Minority carrier lifetime was measured in diffused junction diodes by the storage time method[1] as a function of base layer resistivity and as a function of temperature. The results for both *p*- and *n*-type base regions may be interpreted in terms of recombination levels within the forbidden gap.[2] Curves of log τ *vs* $1/T$ have the same slope for both annealed and quenched samples, indicating that quenching changes the concentration but not the type of recombination centers. The activation energies were 0.51 ev from the valence band in *p*-type and 0.21 ev from the conduction band in *n*-type material. A plot of log τ *vs* reciprocal quench temperature yields information on the energy required to anneal out recombination centers (e.g., 0.66 ev for *n*-type).

[1] M. B. Prince, Bell System Tech. J. **35**, 661 (1956).
[2] W. Shockley and W. T. Read, Phys. Rev. **87**, 835 (1952).

WA3. Semiconductor Surface Potential and Surface States from Field-Induced Changes in Surface Recombination. GEORGE C. DOUSMANIS, *RCA Laboratories.*—Experiments are reported on the effects of ac electric fields and ambients on the surface recombination velocity (s) in silicon and germanium. Changes in s are detected by the variations in the reverse saturation current of large area (0.3 cm²) diodes. The experi-

mental technique is an improved version of that of Thomas and Rediker.[1] Fields up to 10^6 v/cm in the frequency range of 10 to 500 sec^{-1} are used. Both the forward and reverse currents are affected by field and ambient. Phase shift loops, similar to those of field-effect experiments[2] appear at higher frequencies. Observation of a maximum of s provides a reference point from which information is obtained on the zero-field value of the surface potential (ϕ_s) and on the dependence of s on ϕ_s. Large excursions of ϕ_s are obtained over the Bardeen-Brattain cycle of ambients. The results on s *vs* ϕ_s will be discussed in terms of the energy levels, distribution and cross sections of the fast surface states.

[1] J. E. Thomas, Jr., and R. H. Rediker, Phys. Rev. **101**, 984 (1956).
[2] H. C. Montgomery and W. L. Brown, Phys. Rev. **103**, 865 (1956).

WA4. Large Signal Surface Photovoltage Studies in Semiconductors. E. O. JOHNSON, *RCA Laboratories* (introduced by G. C. Dousmanis).—Measurements of the surface photovoltage at low carrier injection levels have been reported.[1,2] In the present experiment, the surface photovoltage as a function of carrier injection over a wide range of carrier densities is reported. Use of ac methods eliminates the need for a vibrating reference electrode and also difficulties with specimen heating and changes in the reference electrode potential. The minority carrier injection level is measured from conductivity changes in the specimen. The observed changes in surface potential with light are plotted as a function of carrier injection level, and the resulting curves compared with those computed from Poisson's equation applied to the surface space charge region. The agreement between theory and experiment is good for both accumulation and inversion layers induced on p- and n-type germanium of different resistivities by various ambients. The effect of fast surface states is discussed.

[1] W. H. Brattain and J. Bardeen, Bell System Tech. J. **32**, 1 (1953).
[2] W. H. Brattain and C. G. B. Garrett, Bell System Tech. J. **35**, 1019 (1956).

WA5. Electrical and Optical Properties of Some $M_3^{V-B}N_3^{VI-B}$ Semiconductors. J. BLACK, C. W. SPENCER, E. M. CONWELL, AND L. SEIGLE.—A number of compounds of V–B and VI–B elements with the chemical formula $M_3^{V-B}N_3^{VI-B}$ have been synthesized as single crystals of 10^{18}–10^{19}/cm^3 carrier concentration. Resistivity, thermoelectric power, infrared transmission, and in some cases, Hall effect has been measured to characterize[1] the following compounds as semiconductors: Sb_2S_3 ($\Delta E=1.68$ ev, $\rho=10^8$ ohm-cm, $Q=+1000$ μv/°C); Bi_2S_3 ($\Delta E=1.3$ ev, $\mu_e=200$ cm^2/v-sec, $\rho=10^{-2}$ ohm-cm, $Q=-750$ μv/°C); Sb_2Se_3 ($\Delta E=1.18$ ev, $\mu_e=15$, $\mu_h=45$ cm^2/v-sec, $\rho=10^6$ ohm-cm, $Q=+1200$ μv/°C); Bi_2Se_3 ($\Delta E=0.35$ ev, $\mu_e=600$ cm^2/v-sec, $\rho=5\times10^{-4}$ ohm-cm, $Q=-100$ μv/°C); As_2Te_3 ($\Delta E=1.1$ ev); Sb_2Te_3 ($\Delta E=0.34$ ev, $\mu_h=270$ cm^2/v-sec, $\rho=2\times10^{-4}$ ohm-cm); Bi_2Te_3 ($\Delta E=0.15$ ev, $\mu_e=800$, $\mu_h=400$ cm^2/v-sec, $\rho=1.6\times10^{-3}$ ohm-cm, $Q=+180$ μv/°C). As in the case of group IV semiconductors and III–V semiconducting compounds, energy gaps decrease and mobilities increase with increasing atomic number.

[1] All the values quoted are at 300°K.

WA6. Acceptor States in Silicon. H. J. HROSTOWSKI AND AND R. H. KAISER, *Bell Telephone Laboratories*.—Recent experiments[1] indicate that the observed line spectra of bound holes in silicon are not consistent with the energy level diagram calculated by Kohn.[2] To permit a more rigorous test of existing theory p-type silicon samples have been investigated under higher resolution over a wider spectral region. In boron doped silicon a strong new absorption has been observed at lower energy (approximately 0.030 ev). Transitions to higher excited states have been observed in both aluminum and gallium doped crystals, and previously unresolved bands[1] at about 0.065 ev have been resolved. These results provide a more complete picture of the spectra of bound holes with more accurate location of the observed transitions. All previous data have been obtained from pulled crystals, now known to contain large concentrations of oxygen.[3] Possible effects of this impurity have been investigated by observations on appropriately doped oxygen free crystals prepared by floating zone techniques.

[1] R. Newman, Phys. Rev. **103**, 103 (1956); Burstein, Picus, and Sklar, *Proceedings of the conference on photoconductivity, Atlantic City, November 4–6, 1954* (John Wiley and Sons, Inc., New York, 1955).
[2] W. Kohn (to be published).
[3] Kaiser, Keck, and Lange, Phys. Rev. **101**, 1264 (1956).

WA7. Angular Dependence of Scattered Infrared in Silicon.* P. P. DEBYE AND S. LEDERHANDLER, *Raytheon Manufacturing Company*.—Infrared absorption measurements on silicon always show a band at 9.1μ in crystals pulled from a quartz crucible. W. Kaiser[1] and H. Hrostowski[2] conclude from their experiments that the band is due to the Si–O bond stretching vibration. One of the authors[3] has shown that the magnitude of the 9.1-μ band is dependent on heat treatment and can be cycled by proper choice of time and temperature. Samples which originally show a sharp band of high absorption can be treated to give a broad band of low absorption. Oxygen does not to any extent diffuse out of the silicon since the 9.1-μ band can be cycled. Changes in the absorption band characteristics can be explained by a change in particle sizes. In fact, infrared scattering has been also observed by Kaiser.[4] We have measured the angular distribution of the scattered infrared radiation in order to obtain information on the particle size. Our measurements indicate that particle sizes are in the order of the wavelength of the light and that they are dependent on heat treatment as is the absorption of the 9.1-μ band. Detailed information will be presented correlating the particle size and the amplitude of the 9.1-μ absorption band.

* Supported in part by the Bureau of Ships, Signal Corps, Air Force.
[1] Kaiser, Keck, and Lange, Phys. Rev. **101**, 1264 (1956).
[2] H. Hrostowski and R. H. Kaiser, Bull. Am. Phys. Soc. Ser. II, **1**, 295 (1956).
[3] S. Lederhandler, Bull. Am. Phys. Soc. Ser. II, **1**, 381 (1956).
[4] W. Kaiser and P. H. Keck, Bull. Am. Phys. Soc. Ser. II, **1**, 321 (1956).

WA8. Infrared Lattice Vibration Studies of Polar Character in Compound Semiconductors. G. S. PICUS, E. BURSTEIN, AND B. W. HENVIS, *U. S. Naval Research Laboratory*.—The far infrared reflection spectra of several III-V compounds have been measured and typical reststrahl reflection peaks characteristic of the optical lattice vibration modes have been found at the following wavelengths: InP, 32 μ; InAs, 41 μ; GaAs 36 μ; GaSb, 40.5 μ; AlSb, 31 μ. The static dielectric constants of these materials were calculated from simple dispersion theory using known values of the optical dielectric constants and the observed widths of the reflection peaks. From this information together with the transverse vibration frequencies estimated from the data an effective ionic charge was calculated using the expression due to Szigeti.[1] The values found are: InP, 0.58; InAs, 0.34; GaAs, 0.50; GaSb, 0.18; AlSb, 0.41. These effective charges represent contributions both from static charge (responsible for ionic binding) and deformation charges arising from neighboring ion interactions when the ions are displaced from their equilibrium positions.

[1] B. Szigeti, Trans. Faraday Soc. **45**, 155 (1949).

WA9. Infrared Optical Constants of Gallium Arsenide.* ARNOLD PERLMUTTER, *University of Miami*.—The transmission and reflectivity of a sample of n-type GaAs have been measured in the region from 0.86 to 25 μ. The free carrier absorption is found to be proportional to the square of the wavelength, beginning at about 7 μ, in agreement with the

Drude-Kronig theory. The effective mass of the conducting electrons, which is determined from these data and the carrier concentration (6.9×10^{17} cm^{-3} at room temperature), is found to be 0.075 or about double the value reported from thermoelectric measurements.[1] Measurements of the reflectivity as a function of the wavelength will also be described. The optical energy gap was found to be about 1.35 ev, a value which is about equal to that found previously[2] A long tail at the absorption edge masks the possible effect of indirect transitions.

* This work was supported in part by Chicago Midway Laboratories and the U. S. Air Force.
[1] Barrie, Cunnell, Edmond, and Ross, Physica **20**, 1087 (1954).
[2] F. Oswald and R. Schade, Z. Naturforsch. **9A**, 611 (1954).

WA10. Field Effect Studies on PbS Films. JAY ZEMEL, *U. S. Naval Ordnance Laboratory.*—The dc field effect on chemically deposited PbS films has been used as a method for investigating the effect of ambient gas and temperature on the slow surface states. As in the case of germanium, the presence of water vapor significantly alters the time constant of the slow states. In both dry oxygen and nitrogen the time constants are effectively infinite. As water vapor is introduced the time constant decreases to times of the order of minutes. As previously reported,[1] the time constants depend on the magnitude of the applied field. The temperature dependence of the time constants in the room temperature range will be discussed as well as the correlation of both ac and dc field effects with the photoconductive behavior of the films.

[1] J. N. Zemel, comment on paper of S. R. Morrison in *Semiconductor Surface Physics*, edited by R. H. Kingston [University of Pennsylvania Press, Philadelphia (to be published)].

WA11. Temperature Effects and Frequency Response in PbS Photoconductive Cells. M. L. HECHT, M. GROSSMAN, AND R. H. TOURIN, *The Warner & Swasey Research Corporation.*—It is known that photoconductivity in PbS varies strongly with temperature, and that the temperature effect is less when the incident light is chopped at high frequencies. A theoretical equation for the relative resistance change $\Delta Z/Z$ caused by chopped light has been derived, assuming (1) N-type material, (2) negligible space charge, (3) recombination time for photoconductive centers much greater than duration of electron-trapping effects, and (4) photoconductivity is due to changes in the number of charge carriers, with electron mobility relatively constant. The analysis yields a "time constant" of $\Delta Z/Z$ which may depend on chopping frequency. $\Delta Z/Z$ may decrease monotonically with T, or go through a maximum. Conditions on the location of the maximum will be described. A secondary photovoltaic effect may occur, which causes sublinear or superlinear response and produces a "second time constant." Measurements of the temperature variation of $\Delta Z/Z$ will be presented and compared to the theoretical equation.

SATURDAY AFTERNOON AT 2:00

Mosaic Room

(D. J. ROSE presiding)

Invited Paper

X1. The Structure of Spectrum Lines Emitted from a Plasma. H. MARGENAU, *Yale University.* (30 min.)

Electron Physics

X2. Disappearance of Spectral Lines with High Quantum Numbers in a Plasma. H. MARGENAU AND D. KELLY,* *Yale University.*—In a plasma of sufficient electron concentration, lines with high quantum numbers disappear for 2 different reasons: (1) The broadening of the levels causes them to merge (Inglis-Teller) and (2) the continuum limit is effectively lowered because the electron moves in a screened (Debye-Hückel) potential rather than a Coulomb field (Unsöld, Ecker, and Weizel). A comparison is here made of the results of different models for the second mechanisms. When the two effects, the merging and the drowning, are studied at different temperatures and electron concentrations, the former determines the greatest permitted quantum number at high temperatures and low densities, but at concentrations of 10^{18} electrons/cc and at 1000°K the levels begin to be drowned rather than merged.

* Supported by the Office of Naval Research.

X3. Class of Exact Solutions of the Vlasov Equations. E. G. HARRIS, *U. S. Naval Research Laboratory.*—In the approximation made in the Vlasov[1] equations the interaction of the electrons and ions of a plasma is taken into account only through the average electric and magnetic fields. These fields are made consistant with the charge and current densities in the plasma. By consideration of the equations of motion of the individual electrons and ions it is possible to find a class of exact solutions of the time-independent Vlasov equations. Solutions have been found which describe a plasma confined by a magnetic field. The method of solution is also applicable to the study of plasma oscillations of finite amplitude.

[1] A. Vlasov, J. Phys. (U.S.S.R.) **9**, 25, 130 (1945).

X4. Simulation of Galactic Evolution in the Laboratory. WINSTON H. BOSTICK,* *Stevens Institute of Technology.*—Several plasma guns fired simultaneously radially inward across a magnetic field produce luminous plasma configurations with spiral arms. Spiral galaxies type *Sb* and *Sc*, and barred spirals (SBb) observed by astronomers can thus be strikingly simulated in the laboratory. The laboratory-observed process suggests that galactic evolution involves the gravitational contraction[1] of ionized hydrogen across a magnetic field. The scaling of the process from laboratory to cosmos will be discussed.

* The experimental work was carried out at the University of California Radiation Laboratory and was sponsored by the U. S. Atomic Energy Commission.
[1] W. H. Bostick, Phys. Rev. **100**, 1007 (1955).

X5. Electron Affinity of Lithium.* M. METLAY AND R. H. PENFIELD, *Harpur College.*—A variational calculation is carried out for the four electron system, using a Hylleraas-type wave function and taking into account the polarization effect of the 1s electrons but not the 2s electron. The electron affinity of the lithium atom comes out to be 0.92 ± 0.01. This is 0.22 ev greater than that obtained by Moiseiwitsch,[1] who

considers only polarization effects for the 2*s* electrons but not for the 1*s* electrons. It is well known that[2] polarization effects of the 1*s* electrons predominate over those of the 2*s* electrons, and it is interesting to see that the electron affinity is lowered when this is done. The coefficients of the wave function used have also been computed and will be reported.

* Supported by the National Science Foundation.
[1] B. L. Moiseiwitsch, Proc. Phys. Soc. (London) **A67**, 25 (1954).
[2] See, for instance, Kun Huang, Phys. Rev. **70**, 197 (1954).

X6. Decay and Recovery of the Pulsed Emission of Thoria and Alkaline Earth Oxide Cathodes. G. MESNARD, G. DÉJARDIN, AND R. UZAN, *Université de Lyon.*—We have comparatively studied the behavior in pulse operation of thoria and alkaline earth oxide cathodes. In both cases, but perhaps more accurately for thoria cathodes, the decay curves are well represented by the formula: $1/i = 1/i_\infty - (1/i_\infty - 1/i_0)\exp(-\alpha t)$, which can be established on the basis of the mobile donor hypothesis. The analysis gives $\alpha = 2\pi^2 D/d^2$, where D is the diffusion constant of the ionized donors and d the thickness of the oxide layer. According to the theory, the durations of the decay and of the recovery should be of the same order of magnitude, as found for thoria cathodes only. The recovery of the usual oxide cathodes, which is much slower than the decay, could possibly be explained by assuming a predominant effect of residual gases at very low pressures, in conformity with the observations of Plumlee on the presence and evolution of gases in the vicinity of a barium oxide cathode.

X7. Effect of Space Charge upon the Negative Townsend Characteristic. A. L. WARD, *Diamond Ordnance Fuze Laboratories.*—Von Engel and Steenbeck[1] have pointed out the role of space charge in the distortion of an electric field in a gas between parallel plates. They used an approximate method to show that the change of voltage caused by the field distortion is proportional to the square of the current density. We have used the more exact method of Crowe, Bragg, and Thomas[2] to calculate the effect of space charge formation on the static characteristics of the rare gases. Numerical computations were performed by the National Bureau of Standards Computation Laboratory on SEAC. Our results show that the relation of voltage and current density determined by Von Engel and Steenbeck is obeyed over a considerable range of current density. Variation of static characteristics with various gas parameters and gap widths will be shown. Favorable comparisons of the computed characteristics with experimental data taken in this laboratory have been made in a limited number of cases.

[1] A. Von Engel and M. Steenbeck, *Elektrische Gasentladungen* (Verlag Julius Springer, Berlin, 1934), Vol. II, pp. 48–57.
[2] Crowe, Bragg, and Thomas, Phys. Rev. **96**, 10 (1954).

X8. Reflection of Very Slow Electrons from Surfaces of Pt and Ge.* H. A. FOWLER AND H. E. FARNSWORTH, *Brown University.*—A nearly monoenergetic beam from a single-focusing electrostatic analyzer is used to measure reflection coefficients of polycrystalline platinum and single-crystal germanium [(100) face]. Primary energies as low as 0.1 to 0.2 ev are obtained. Geometrical $\Delta V/V$ of the analyzer is 3%; the beam is transmitted at 4.8 ev; 70 to 80% of the output current is observed in the expected range ΔV. The output beam is refocused and decelerated before entering the target region. Cpd between target and collector is measured and compensated by the Kelvin method. Targets are cleaned by heating and argon-ion bombardment. Ion-bombarded surfaces show R approaching zero smoothly near zero primary energy. Outgassed platinum shows a maximum at 2.5 ev, and a large rise in apparent R near zero, attributable to the patch effect of crystal grains. The importance of a uniform target work function is indicated. Germanium, after HF etch, shows a high R (0.40–0.60) between 5 and 2 ev, which drops rapidly at lower energies. Preliminary results after cleaning show a low R (<0.15) at 5 ev, which decreases smoothly with decreasing energy.

* Assisted by the Research Corporation of New York.

X9. Angular Distribution of Characteristic Energy Losses.* J. AROL SIMPSON, M. D. WAGNER, AND L. MARTON, *National Bureau of Standards.*—The distribution in energy and angle of 20-kev electrons scattered by metal foils has been remeasured using a new apparatus[1] based on electrostatic deceleration and magnetic dispersion. The energy resolution is limited by the half-width of the initial beam to ~1 ev. The angular resolution is $\sim 10^{-4}$ radians. These values are an order of magnitude better than those previously reported.[2] In aluminum the 7, 14, 21, and 28-ev characteristic losses are fully resolved and can be followed out in angle. The change in characteristic loss value with angle reported by Watanabe[3] is confirmed. However, the distribution of intensity is not what would be expected. The conclusions suggested by these results will be discussed.

* Supported in part by the Office of Naval Research and the U. S. Atomic Energy Commission.
[1] Being developed with the support of the Office of Basic Instrumentation.
[2] Simpson, McCraw, and Marton, Phys. Rev. **104**, 64 (1956).
[3] H. Watanabe, J. Phys. Soc. Japan **11**, 112 (1956).

X10. Inelastic Scattering of Electrons in Metal Vapors.* LEWIS B. LEDER AND L. MARTON, *National Bureau of Standards.*—An electrostatic analyzer previously used for measuring energy losses of electrons in thin films of metals[1] was modified for the measurement of energy losses of 20-kev electrons in metal vapors. These measurements are similar to the critical potential measurements made elsewhere at much lower energies. The electron beam was directed perpendicular to a tubular oven and passed through two 10 mil holes in the oven wall, encountering the metal vapor in the half-inch path. The oven was heated by passing current directly through it, the return path being a concentric copper tube. Preliminary measurements have been made for K, Zn, Cd, Hg, and Te vapors. Energy losses corresponding to known excitations of the valence electrons were found. In addition we have found several energy losses greater than the ionization potentials of the respective metals which do not appear to be correlated with transitions in the ionized atoms. The energy loss values and their possible relationship to the characteristic energy losses of electrons in solids[1] will be discussed.

* This work was in part supported by the U. S. Atomic Energy Commission.
[1] Marton, Leder, and Mendlowitz, Advances in Electronics and Electron Phys. **VII** (1955).

SATURDAY AFTERNOON AT 2:00

Panel Room

(F. AYZENBERG-SELOVE presiding)

Nuclear Reactions and Nuclear-Energy Levels, IV

XA1. (n,p) Reactions for Several Middle-Weight Elements.* V. V. VERBINSKI, T. HURLIMANN, W. E. STEPHENS, AND E. J. WINHOLD, *University of Pennsylvania.*—Protons emitted from thin foils of Mg, Ni, Cu, and Rh bombarded with 14-Mev neutrons have been detected with a view to obtaining information on the interaction of the incident neu-

tron with the target nucleus. Proton energy and angular distributions and emission cross sections have been measured for protons of energies greater than 4 Mev. (D,T) neutrons from our electrostatic generator were collimated by three feet of iron and struck a target foil viewed by thin CsI scintillation counters placed at 30°, 45°, 60°, 90°, 120°, 135°, and 150° to the neutron beam. The background in these counters was reduced considerably by counting only pulses in coincidence with those alpha particles from the neutron source which were associated with the neutron beam. For each target investigated, there appears to be more protons emitted at forward angles than backward. For example, the number of protons from nickel detected at 45° is about 1.8 times the numbers at backward angles. The largest forward asymmetry found was for the high-energy protons from magnesium. These observations indicate that a relatively direct interaction between incident neutron and emitted proton may often occur.

* Supported by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

XA2. Radiative Proton Capture Q Values in the Region, $60 \leq A \leq 66$. C. R. Gossett, *U. S. Naval Research Laboratory.*—As part of a program of determining mass differences in the intermediate mass region, the ground state Q values of several (p,γ) reactions with nuclei of mass numbers between sixty and sixty-six have been measured by crystal spectrometer techniques. Bombarding protons were supplied by the NRL 2-Mev Van de Graaff accelerator, and the capture gamma rays detected with a 3- by 3-in. NaI(Tl) crystal. Conventional electronics, including a twenty-channel pulse-height analyzer, were used in the measurements. Well-known light-element (p,γ) reactions provided energy calibration, the energies of these gamma rays being known from high-precision, magnetic charged-particle spectroscopy. To minimize gain shifts in the detection system, calibrations were made frequently, and the intensities of the gamma rays from the reaction and the calibrating reaction were adjusted to be approximately equal. Targets, 10 to 20 kev thick, were prepared by electrodeposition onto gold blanks. Preliminary ground state Q values have been obtained for the following target nuclei (in units of Mev): Ni^{60}, 4.82; Ni^{61}, 5.79; Cu^{63}, 7.69; and Cu^{65}, 8.85. The probable errors of these measurements are believed to lie within the range of 30 to 50 kev.

XA3. Coulomb Excitation of Enriched Kr Samples. G. F. Pieper and N. P. Heydenburg, *DTM, Carnegie Institution of Washington,* and C. E. Anderson, *Yale University.*—Normal Kr and two different samples of Kr, enriched in Kr^{78}, Kr^{80}, and Kr^{82} were Coulomb excited by 6.1- and 6.6-Mev alpha particles. The following first excited state transitions $(0^+ - 2^+)$ were observed: Kr^{78}, 450 kev; Kr^{80}, 620 kev; Kr^{82}, 780 kev; and Kr^{84}, 880 kev. We[1] had previously assigned the 450-kev gamma ray to Kr^{83}; the observed gamma ray at this energy in normal Kr is consistent with the assignment to Kr^{78} and no gamma rays were observed which could be attributed to Kr^{83}. Due to difficulties associated with the use of gas targets, we have only relative intensity measurements of the gamma rays and hence give the following relative $B(E2)$ values: Kr^{78}, 0.83; Kr^{80}, 0.29; Kr^{82}, 0.088; and Kr^{84}, 0.056, where the value for Kr^{84} was arbitrarily taken to agree with that observed for Se^{82} (Se^{82} and Kr^{84} have same N and ΔE).

[1] N. P. Heydenburg and G. M. Temmer, Bull. Am. Phys. Soc. Ser. II, **1**, 164 (1956).

XA4. Coulomb Excitation of 2^+ States in Even-Even Isotopes of Tin and Zirconium. P. H. Stelson and F. K. McGowan, *Oak Ridge National Laboratory.*—Coulomb excitation of 2^+ states in the even-even isotopes of tin and zirconium has been observed by bombarding targets of the normal elements with 9.0- and 10.0-Mev doubly ionized α particles accelerated by the ORNL 5.5-Mv electrostatic generator. The known 2^+ states for several of the tin isotopes are Sn^{114}, Sn^{116}, Sn^{120}, and Sn^{122} at 1.30-, 1.27-, 1.18-, and 1.15-Mev, respectively. A composite γ-ray peak with an average energy of 1.20 Mev is observed when tin is bombarded. The variation in γ-ray yield with α-particle energy is consistent with that expected for Coulomb excitation. The angular distribution of the γ rays exhibits the strong anisotropy characteristic of Coulomb excitation of 2^+ states. A single γ ray with an energy of 0.92 Mev is observed when zirconium is bombarded. The 2^+ states in Zr^{92} and Zr^{94} are known to be at 0.92 Mev from other work. The average $B(E2)_{av}$ (reduced transition probability for electric quadrupole excitation) for the 2^+ tin states is $(2.1 \pm 0.4) \times 10^{-49}$ cm^4 and that for the 2^+ states of Zr^{92} and Zr^{94} is $(0.80 \pm 0.12) \times 10^{-49}$ cm^4. These transition rates are larger than those given by the independent particle estimates by a factor of 12 for the tin isotopes and by a factor of 6 for Zr^{92} and Zr^{94}.

XA5. Gamma Ray Precision Spectroscopy.* A. F. Clark, J. W. M. DuMond,† F. Gordon, and Hans Mark, *University of California, Livermore.*—The 3.7-Mev proton beam from the A-48[1] has been used to study gamma rays following electric excitation of wolfram (tungsten). 5 ma gave a source strength of about 100 mC. A quartz crystal bent to a 2-m radius, similar to DuMond's instrument[2] focused the gamma rays on a glass plate, which had on it a 600-μ nuclear emulsion. Gamma-ray lines at 100.1, 111.1, and 122.4 kev are from the first excited states of W^{182}, W^{183}, and W^{184}, respectively,[3] and lines at 46.5 and 52.6 kev come from the first and second levels in W^{182}. X-ray and known gamma-ray lines[4] are used for calibration. Preliminary measurements are accurate to 0.3%.

* Work supported by the U. S. Atomic Energy Commission.
† California Institute of Technology.
[1] E. O. Lawrence, Science **122** No. 3180, 1127 (1955).
[2] J. W. M. DuMond, Rev. Sci. Instr. **18**, 626 (1947).
[3] McClelland, Mark, and Goodman, Phys. Rev. **93**, 904 (1954).
[4] Boehm, Marmier, and DuMond, Phys. Rev. **95**, 864 (1954).

XA6. Angular Distributions of Gamma Rays following Electric Excitation of Some Low-Lying Rotational States.* R. P. Scharenberg and G. Goldring, *M. I. T.*—An investigation was carried out of the angular distribution of gamma rays from the 2^+ states of Sm^{152} and natural W following electric excitation by protons of 2.1 Mev. Angular distributions from metal targets were found to be perturbed as expected; however, the distributions were not reduced to the "hard core." The attenuation coefficient G_2 was found to be 0.65 ± 0.06 in Sm metal and 0.80 ± 0.08 in W metal. A liquid Sm target was prepared by dissolving 40 mg of $Sm^{152}(NO_3)_3$ in 0.07 cc of water. For this target, the attenuation coefficient was found to be 0.95 ± 0.05. The angular distribution of proton bremsstrahlung from various targets was also investigated in the course of this work. The most accurate measurement to date was made with Pb. The Bermsstrahlung from Pb of 135 kev was found to have the distribution $1 + A_2 P_2(\cos\theta)$ with $A_2 = -0.25 \pm 0.03$; whereas from the calculations of Alder and Winther,[1] one obtains $A_2 = -0.21$.

* This work was supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Committee.
[1] K. Alder and A. Winther, CERN/T/KA-AW-4 (October, 1955).

XA7. Anomalous Inelastic Scattering of 23-Mev Protons by Heavy Elements. Bernard L. Cohen, *Oak Ridge National Laboratory.*—Measurements of energy distributions from inelastic scattering of 23-Mev protons by various heavy elements indicate the presence of very strong, apparently monoenergetic groups. The energies, cross sections, and angular distributions of these proton groups vary slowly and regularly with atomic number. For example, the proton energy spectrum from $-Q = 0.8$ to 3.6 Mev for all elements between $Z = 40$ and 52 can be accounted for by groups with $-Q \cong 1.2$, 2.3, and 3.0 Mev with cross sections $\cong 3$, 11, and 7 mb, respectively. There is little or no difference between even and odd elements, or across the closed shells at $N = 50$ and $Z = 50$. The spectra from

lead and bismuth are practically identical to $-Q=7$ Mev, consisting, apparently, of six monoenergetic groups. The well-known $-Q=2.6$ Mev level in lead is strongly excited, and there is a group from bismuth with the same energy, cross section, and angular distribution. The regularities between odd and even elements and across closed shells complicates explanations of the levels by single particle or collective models. For $-Q$ up to 8–10 Mev, the energy distributions show very marked deviations from smoothness; this may indicate that relatively few levels of the final nucleus participate in the reaction.

XA8. (Abstract withdrawn.)

XA9. Dependence of the Average Charge of an Ion on the Density of the Surrounding Medium. JACOB NEUFELD, *Oak Ridge National Laboratory*, AND W. S. SNYDER, *Oak Ridge National Laboratory and the University of Tennessee.*—Recent experiments by Lassen revealed the existence of a "density effect" expressing the dependence of an average charge of an incident fission fragment on the density of the surrounding medium. It was suggested that the effect may be due to a polarizing field which causes spontaneous emission of electrons carried by the fission fragments and this tends to increase their average charge. In order to account for this effect various electronic orbits of a moving fission fragment have been separately considered and the corresponding polarizing fields that are sufficiently strong to produce autoionization have been determined. A relationship has been established between various values of the polarizing field and the corresponding average charge of an incident fission fragment. The orbital electrons in a moving fission fragment are continually maintained in an excited state because of the recurrent collisions of the atoms in the surrounding medium and, therefore, in establishing the above relationship various excitation states of the moving fission fragment have been considered.

XA10. Fission Cross Section of U^{233}.* L. G. MILLER, R. G. FLUHARTY, R. M. BRUGGER, AND M. S. MOORE, *Phillips Petroleum Company.*—The Materials Testing Reactor fast chopper and a multiplate fission chamber have been used to measure the fission cross section of U^{233} in the neutron energy range 1.0 to 1000 ev. Individual resonances are well resolved below 15 ev. Levels are observed at the following energies: 1.78 ev, 2.3 ev, 3.6 ev, 4.45 ev, 4.73 ev, (5.0 ev), 5.9 ev, 6.85 ev, (7.6 ev), 8.63 ev, 9.3 ev, 10.45 ev, 11.44 ev, (12.1 ev), 12.78 ev, and 13.6 ev. Levels in parentheses have not previously been reported. An area analysis is being made on the data. Preliminary results give an average level spacing of 0.75 ev and an average fission width of $\bar{\Gamma}_f=0.165$ ev. The multilevel dispersion fit to the data below 4 ev[1] is being extended to the higher levels. Parameters for the individual levels will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Moore, Miller, and Reich, Bull. Am. Phys. Soc. Ser. II, 1, 327 (1956).

XA11. γ Rays from Fission of U^{235} Induced by Thermal Neutrons.* C. C. TRAIL AND C. M. HUDDLESTON, *Argonne National Laboratory.*—The angular correlation between fission fragments and fission γ rays has been studied using a gas scintillation counter and a NaI crystal in coincidence. The fission counter subtended a 2π solid angle and the γ-ray counter subtended a 1% solid angle. Preliminary results indicate that the γ rays are emitted preferentially in the same hemisphere as the lighter fission fragment. Moreover, this correlation appears to increase as γ-ray energy increases.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

XA12. Fission and Capture Cross Section of U^{235} for Slow Neutrons.* F. J. SHORE AND V. L. SAILOR, *Brookhaven National Laboratory.*—The fission cross section of U^{235} has been measured[1] with the Brookhaven National Laboratory crystal spectrometer over the energy range from 0.1 to 10 ev. The capture cross section is obtained with good accuracy by subtracting the sum of the scattering[2] and fission cross sections from the total cross section which has been measured[3] previously on the same instrument under identical conditions of resolution. It has been reported[3] previously that resonances in the U^{235} total cross section do not have a shape consistent with the Breit-Wigner single-level formula; i.e., it appears that a many-level formula will be required to give a reasonable fit to the data. The new fission data show that the asymmetry lies in the fission component of a given resonance; whereas the capture component is quite symmetrical and can be fit with a single level formula. The data yield more precise values of $g\Gamma_n$, Γ, Γ_f, and Γ_γ for many of the resonances below 10 ev.

* Work performed under contract with the U. S. Atomic Energy Commission.
[1] The fission chamber used in the measurements was kindly loaned to us by W. W. Havens, Jr., of Columbia University.
[2] H. L. Foote (unpublished).
[3] V. L. Sailor, Peaceful Uses of Atomic Energy, *Proceedings of the International Conference in Geneva* (Columbia University Press, New York, 1955), Vol. 4, p. 199.

XA13. Neutron-Induced Fission of Ra^{226}.* RALPH NOBLES, J. H. MANLEY,† AND R. B. LEACHMAN, *Los Alamos Scientific Laboratory.*—The energy distributions of fragments from neutron-induced fission of Ra^{226} have been observed for neutron energies of 4.5, 8.5, and 22 Mev. Neutrons were obtained from the large Los Alamos Van de Graaff using the $T(p,n)$, $D(d,n)$, and $T(d,n)$ reactions. The observations were made by using a xenon-filled gas scintillation counter looking at single fragments from a 8-μg/cm^2 Ra^{226} deposit. Advantage was taken of the linearity and high speed of the gas scintillation process to differentiate between the radium alpha particles and the fission fragments. Pulses from a RCA-6342 with a quaterphenyl wave shifter were sent directly into a crystal diode discriminator circuit which was biased to pass only the fission pulses. These fission pulses were then amplified by a Model 101 linear amplifier and analyzed for pulse height. Preliminary data indicate the mode of fission is mainly asymmetric for 4.5-Mev neutrons and predominately symmetric for 22-Mev neutrons. A more complicated mass yield has previously been found for 11-Mev proton induced fission of Ra^{226}.[1] The energy distribution for 8.5-Mev neutron induced fission similarly shows a complicated structure.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Permanent address: University of Washington.
[1] A. W. Fairhall and R. C. Jensen, University of Washington Cyclotron Research Report (1956) (unpublished).

SATURDAY AFTERNOON AT 2:00

Boston-Washington Room

(H. FESHBACH presiding)

Theoretical Physics, VI: Low-Energy Scattering

Y1. Complex Potential Model with Diffuse Boundary and Surface Absorption.* W. S. EMMERICH AND H. J. AMSTER, *Westinghouse Electric Corporation.*—Further comparison of the fast neutron cross sections and angular distribution of elastic scattering have been completed at energies ranging from 2.5 to 14 Mev. Models were computed with the real part of the potential consisting of a constant spherical core and a diffuse surface, $(e^x-x)^{-1}$ times the value in the core, where $x=(r-R_c)/\tau$. R_c is the radius of the core and τ, a diffuseness parameter. The imaginary part was taken as λ times the derivative of the real part with respect to x. The surface absorption models have the advantage that λ is practically independent of mass number, whereas in the volume absorption models the corresponding quantity ζ must be varied. Comparison of the angular distribution has not so far resulted in a decisive preference for the surface absorption model. Average values for the best parameters of the potential have been computed from the available experimental data and will be presented to show the dependence on neutron energy and mass number.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

Y2. Optical Model Analysis of Proton-Nucleus Scattering.* P. J. KELLOGG AND A. E. GLASSGOLD, *University of Minnesota.*—Studies of proton-nucleus scattering with the optical model have been extended to 17 Mev.[1] The calculations are being carried out on the Univac Scientific Computer.[2] Angular distributions for scattering from C, Al, Cu, Ag, and Au will be presented and compared with the data of Dayton and Schrank.[3] In addition Peele's data on the scattering by carbon of protons of energies between 14 and 20 Mev has been analyzed.[4] The optical model parameters obtained at these energies will be compared with the previous results at 10 Mev.

* Supported in part by U. S. Atomic Energy Commission.
[1] Glassgold, Cheston, Stein, Schuldt, and Erickson, Bull. Am. Phys. Soc. Ser. II, 1, 339 (1956).
[2] The authors are indebted to the Sperry-Rand Corporation for the use of their St. Paul computing facilities.
[3] I. E. Dayton and G. Schrank, Phys. Rev. 101, 1358 (1956).
[4] The authors would like to thank Dr. R. W. Peele for communicating his results prior to publication.

Y3. Inelastic Scattering by Central Potentials.* ROGER G. NEWTON, *Indiana University.*—The problem of multiple channel reactions occurs in ordinary scattering of a particle by a system which may be left in an excited state, and in scattering in the course of which the scattered particle may change its identity and therefore its mass and kinetic energy. Such reactions may be described by a set of coupled Schrödinger equations for the wave functions of the various channels. If the "potentials" are local and central, one may apply a partial wave analysis. Eigenphase shifts are introduced and their properties investigated in the case of two channels. In general, the phase shift of one particle, and its derivative, have a discontinuity at the threshold for production of the other. There may be bound states of particle No. 2 below the threshold of their production by No. 1. Small perturbations will in general lead to transitions of the bound particle No. 2 to the unbound No. 1, and hence will destroy the bound state by giving it a finite lifetime. This is accompanied by the appearance of a resonance in the elastic scattering of particle No. 1 at the energy of the perturbed bound state of No. 2. Other properties and possible applications will be discussed.

* Supported by the National Science Foundation.

Y4. Noncentral *n-p* Potentials from Scattering and Bound State Data.* T. FULTON, *The Johns Hopkins University,* AND R. G. NEWTON, *Indiana University.*—The method of constructing potentials from a given S matrix and bound state data[1] has been applied to the case of the *n-p* interaction in the triplet state. Three parameters are used. They are fixed by the values of the effective range, the deuteron binding energy and the D-state admixture in the scattering (determined by the value of the deuteron quadrupole moment). A suitable extrapolation of the S matrix is made to all energies from the above data. The procedure is exact from this point on. A one parameter family of central, tensor, and spin-orbit potentials is algebraically determined. The corresponding bound state and scattering wave functions are also obtained. The value of the D-state probability in the deuteron restricts the possible values of the free parameter, which is essentially a measure of the spread of the wave functions. Plots of the potentials and the wave functions will be exhibited.

* Supported by the National Science Foundation.
[1] See T. Fulton and R. G. Newton, Nuovo cimento X, 3, 677 (1956) and references there to previous work.

Y5. Effect of Polarization in *n-d* Scattering.* L. SARTORI, *Brookhaven National Laboratory,* AND S. I. RUBINOW, *Stevens Institute of Technology.*—Because of the calculational difficulties associated with the neutron-deuteron scattering problem, previous efforts have always been based on a no-polarization approximation. In order to examine the possible importance of polarization in the low-energy scattering, we have utilized an improved variational method with a wave function which includes a polarization parameter. Stationary expressions give the S-wave phase shifts explicitly in terms of an inside wave function, which vanishes except when all three particles are within the range of interaction. Central Gaussian potentials with arbitrary exchange character are used to represent the effective nucleon-nucleon interaction, and the trial functions are also Gaussian in nature. The numerical computations were performed on the MIT. Whirlwind I digital computer. Results with a two-parameter trial function seem to indicate little effect of polarization in either the doublet or quartet spin state. The scattering lengths obtained are not in numerical agreement with either of the two sets which are experimentally allowed, but they appear to favor the set in which the quartet scattering length is greater. In the no-polarization limit our results are not in complete agreement with those of earlier calculations. Computations using a more general four-parameter trial function are in progress.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research. Most of this work was performed while the authors were at Massachusetts Institute of Technology.

Y6. Nuclear Cross Sections for the Scattering of Neutrons and Protons. R. JASTROW AND I. HARRIS, *U. S. Naval Research Laboratory.*—Calculations of cross sections and polarization effects in the scattering of neutrons and protons have been carried out for aluminum, iron, and lead. The calculations assume a complex central potential well of rounded form, plus a Thomas spin-orbit interaction. Phase shifts are computed in WKB approximation. Comparison with data on scattering and polarization at 310 Mev permits the determination of nuclear radii and surface thickness. We find that knowledge of the polarization is essential, the scattering data alone being inadequate for the determination of these parameters. Further calculations are in progress on scattering by neutrons and

protons, at low energies, using an exact phase-shift analysis, and assuming an arbitrary radial variation of the absorption coefficient.

Y7. Analysis of p-p Scattering at 32 Mev.* H. P. NOYES, *University of California, Livermore.*—As has been shown by Raphael,[1] knowledge of the $^1S_0$ nucleon-nucleon phase shift in the 30–40-Mev region might allow a demonstration of short-range repulsion in the singlet state at an energy where there is some hope that a static potential description of the interaction is still valid. Additional evidence for short-range repulsion would consist of showing that the $^1D_2$ phase is significantly smaller than 0.8° (the smallest D phase to be expected at 32 Mev from a monatomic potential fitted to the p-p effective range and scattering length[2]) Knowledge of the ^3P phases might help untangle a significant vacuum polarization effect.[3] Unfortunately, existing data[4] do not allow a conventional phase shift analysis to be made. However, it is possible to investigate numerically what continuous sets of values of the phase shifts are allowed, and a Univac code has been developed for this purpose. Results will be presented.

* Research supported by the U. S. Atomic Energy Commission.
[1] R. B. Raphael, Phys. Rev. **102**, 905 (1956), and lectures at Livermore.
[2] R. S. Christian and H. P. Noyes, Phys. Rev. **79**, 85 (1950).
[3] Eriksen, Foldy, and Rarita, Phys. Rev. **103**, 781 (1956).
[4] W. K. H. Panofsky and F. L. Fillmore, Phys. Rev. **79**, 57 (1950); Cork, Johnston, and Richman, Phys. Rev. **79**, 71 (1950).

Y8. Excitation of Nuclear Rotational Motion by Neutron Scattering.* D. M. CHASE AND L. WILETS, *Los Alamos Scientific Laboratory.*—Neutrons are assumed to interact with strongly deformed target nuclei via a spheroidal, diffuse, complex potential well presented by the target. Only excitation of rotational levels is considered. The target is assumed to be even-even (spin zero). A Tamm-Dancoff approximation is made, in which states with target spin $I \geq 6$ are omitted. The resulting set of coupled differential equations for the various radial wave functions is integrated numerically through the region of changing potential. Excitation functions for the rotational levels $I=2$ and $I=4$ have been studied as functions of deformation, diffuseness, and potential; they have been calculated especially for parameters characteristic of specific nuclei of interest. At reasonable deformations cross sections are, as expected, much smaller than those calculated from a distorted-wave Born approximation, but still comparable with cross sections for compound nucleus formation. Excitation functions will be compared with those obtained from the Wolfenstein-Hauser-Feshbach theory. The effect of the deformation and rotational coupling on total cross sections and other quantities of the spherical complex well model will be noted. It is hoped also to present results for angular distributions.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y9. Neutron Scattering from Nonspherical Nuclei.* KIRK W. MCVOY, *Brookhaven National Laboratory.*—Numerical computations[1] of Γ_n/D as a function of A for zero-energy neutron scattering from spheroidal nuclei, assuming identical deformations throughout the rare-earth region as a model, have shown the S-wave resonance at $A=150$ to be split by the deformation into a main peak and one or more satellite peaks. This demonstrates clearly that scattering from randomly oriented spheroidal potential wells is not equivalent to scattering from a spherical, diffuse-edge well. We wish to point out that a simple perturbation calculation, expanding the potential and the scattering-length in powers of the nuclear deformation, is adequate to explain the origin of the subsidiary resonances. The splitting is not due to the removal of a degeneracy, but rather to the mixing of partial spherical waves caused by the nonspherical potential. An even-order deformation mixes even-l phase shifts into the S-wave phase shift in such a way that, even at zero energy, all even waves for which $l \lesssim K_0 R$ contribute resonances to the reaction cross section. These occur at or near their resonance positions for scattering from spheres, and shift in opposite directions for prolate and oblate deformations. It is interesting to speculate that odd-order deformations, might be in part responsible for the asymmetry of Γ_n/D about $A=150$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Y10. Scattering by Nonspherical Nuclei.* J. MAYO GREENBERG, *Rensselaer Polytechnic Institute.*—Approximation methods developed for high energy potential scattering[1] have been applied to the scattering from randomly oriented nonspherical obstacles. The results for small angle scattering are in form very similar to that of scattering by spheres and are thus quite simple. The total cross section for scattering by a uniform distribution of orientations may be readily calculated for two extreme cases: (1) $kR \gg 1$, $kR(V/E) < 1$, and (2) $kR \gg 1$, $kR(V/E) \gg 1$ where k is the wave number, R is a linear measure of the size of the obstacle, V is the potential (real or complex), and E is the energy of the incident particles. Scattering of neutrons, from spheroidal nuclei with appropriate complex potentials will be discussed.

* Work supported by a grant from the National Science Foundation.
[1] L. I. Schiff, Phys. Rev. **103**, 443 (1956).

Y11. Theoretical Investigation of Alpha-Alpha Scattering.* CHARLES H. HUMPHREY,† *Lockheed Aircraft Corporation.*—Recently measurements on alpha-alpha scattering have been performed at the Rice Institute by Phillips *et al.* from 3 to 6 Mev and at Illinois by Nilson from 12 to 20 Mev. In combination with previous results they give a reasonably complete picture of the alpha-alpha scattering phase shifts from zero to 22 Mev. Phase shifts have been calculated[1] for two types of potentials: (1) The model proposed by Haefner[2] with various values of q^2, r_0, and D, and (2) a square well potential with infinitely hard core. It is possible to fit the S-wave phase shifts from zero to 20 Mev with a number of different sets of parameters. The D and G phase shifts can then be fitted by adjusting these potentials in a uniform way. Comparisons with experimental results will be presented.

* Supported in part by Office of Naval Research and Office of Ordnance Research.
† Formerly at the University of California, Los Angeles, where most of this work was done.
[1] The calculations were performed on the SWAC, Numerical Analysis Research Project, University of California, Los Angeles, with the aid of Dr. M. A. Melkanoff.
[2] R. R. Haefner, Revs. Modern Phys. **23**, 228 (1951).

SATURDAY AFTERNOON AT 2:00

North Ballroom

(L. SPITZER presiding)

Invited Papers

Z1. Californium 254, Supernovae, and the Formation of the Elements. W. A. FOWLER, *California Institute of Technology.* (30 min.)

Z2. Radio Emission from the Sun. LEONA MARSHALL, *University of Chicago.* (30 min.)

Post-Deadline Papers, If Any

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Green, M. S.—R7
Greenberg, J. Mayo—Y10
Greenwald, S. W.—FA5
Gross, Edward E.—D5
Grossman, M.—WA11
Gursky, Martin L.—R4
Guth, Eugene—GA5

Haeberli, W.—K8, K11
Hafner, E. M.—C7, D3
Hahn, B.—D2
Hahn, J.—NA3
Halbert, M. L.—U2, U3
Halpern, Francis—B4
Halpern, I.—J9
Hamermesh, Bernard—SA9
Handley, T. H.—U3
Hanna, S. S.—J5
Hanson, R. J.—B1
Harbottle, G.—G10
Harding, R. S.—C7
Harris, E. G.—X3
Harris, G.—B8, F11
Harris, I.—Y6
Harris, Isadore—MA10
Harvey, J. A.—NA8
Havens, W. W., Jr.—NA3, NA5, NA6, NA11
Hecht, M. L.—WA11
Hellens, Robert L.—E8
Helmer, R. G.—E3
Hempstead, C. F.—SA6
Henri, V.—F7
Henshaw, D. G.—BA13
Henvis, B. W.—WA8
Herb, R. G.—C11
Heydenburg, N. P.—U10, XA3
Hickok, R. L.—G7, NA1
Hicks, Bruce L.—PA8, PA9
Hill, F. K.—Q1
Hines, R. L.—EA7
Hinman, George—D4
Hintz, Norton M.—D6
Hoang, T. F.—F9
Hofstadter, R.—D2
Holzman, G. R.—JA10
Honig, Richard E.—KA2
Horie, H.—J6
Hornbostel, J.—F10
Hornyak, W. F.—B12
Horstman, Henry—D4
Houck, F. S.—U5
Hrostowski, H. J.—WA6
Huddleston, C. M.—XA11
Hughes, D. J.—NA8, NA10, NA12
Hughes, V. W.—M5, M6, M10, SA4
Humphrey, Charles H.—Y11
Hurlbut, F. C.—PA3
Hurlimann, T.—XA1
Hutson, A. R.—T4

Inghram, Mark G.—P10

Jackson, D. A.—SA5
Jahn, Robert G.—Q10
Janin, J.—P4
Janis, Allen—CA4
Jastrow, R.—GA3, GA4, S2, Y6
Jeffries, C. D.—W2
Johnson, E. O.—WA4
Johnson, J. H.—U7
Johnson, Noah R.—G4
Jones, C. M.—RA1
Jones, D. R.—B3
Jones, K. R.—R2
Jones, K. W.—J11, RA7, RA9
Jones, Lawrence W.—C5, C6, C10
Jones, P. R.—KA4
Joseph, P. J.—C11

Kaiser, R. H.—WA6
Kammer, E. W.—TA7
Kane, Gabriel—F12
Kane, J. V.—G11
Kao, S. K.—D4
Kaplon, M. F.—F9
Karplus, Robert—B4
Karriker, F. P.—K7
Kawaguchi, Masaaki—MA3
Kelly, D.—X2
Kellogg, P. J.—Y2
Kieffer, L. J.—P9
King, R. W.—GA8, GA9
Kinney, F. E.—K14
Kittel, Charles—N4
Kivelson, D.—JA8
Klein, Abraham—MA5, UA3
Klein, Lewis—SA3
Klein, Martin J.—BA8
Kloepper, R. M.—U6
Knight, J. M.—CA12
Knowles, J. W.—E5
Kolb, A. C.—Q7
Koth, W.—JA10
Kraichnan, Robert H.—PA5
Kreger, W. E.—D8
Krumbein, A. D.—T9
Kruse, T. H.—J12, RA8
Kurti, N.—VA1

Lampert, Murray A.—T3
Larson, D. C.—EA9
Larson, Q. V.—G5
Laster, Howard—S3
Lazar, N. H.—E1
Leachman, R. B.—XA13
Leavitt, C. P.—F4
Leder, Lewis B.—X10
Lederhandler, S.—WA7
Lee, D. M.—V5
Leipuner, L. B.—B11, B12
Leiss, J. E.—B7
Leming, Howell E.—G1
Levine, M. A.—BA1
Levinger, J. S.—R3, UA7
Lewis, H. W.—K11, RA6, U12
Lichtenberg, D. B.—MA4
Lide, David R., Jr.,—P7, P8
Lidofsky, L. J.—J11, RA7, RA8, RA9
Lin, C. C.—H1
Lind, David A.—K3, U6
Lindenbaum, S. J.—UA4
Lindsay, Robert—FA1
Litherland, A. E.—RA2, RA3, RA4, RA5
Littauer, Rapheal—B6
Livingston, R. S.—C1
Lomon, E.—UA2
Long, Donald—T8
Longe, Pierre—SA10
Low, W.—M2
Lurio, A.—M5, M6
Lyon, W. S.—E1

MacDonald, W. M.—GA12
Macklin, R. L.—E1, E11
Macmillan, S.—NA4
Madigan, J. R.—WA2
Mallet, W.—D8
Mandeville, C. E.—G9, K6, U4
Manley, J. H.—XA13
Mann, A. K.—A4
Mann, D. E.—P7, P8
Marder, S.—M10
Margenau, H.—X1, X2
Mark, Hans—XA5
Markham, A. H.—V4
Marshak, H.—K7
Marshak, R. E.—MA1
Marshall, Leona—Z2
Masket, A. V.—E11
Mason, C. M.—KA6
Marton, L.—X9, X10
Matsen, F. A.—P1
Maxson, D. R.—J6
McCormick, B. H.—MA5
McGowan, F. K.—XA4
McGuire, T. R.—FA5
McIntyre, John A.—D1
McKeown, M.—G10
McKim, F. R.—BA2
McKinley, W. A.—G7
McManus, Hugh—G2
McReynolds, A. W.—FA3
McVoy, Kirk W.—Y9
Melkonian, E.—NA11
Merlic, E.—PA3
Merzbacher, E.—K9
Mesnard, G.—X6
Metlay, M.—X5
Metropolis, N.—UA10, UA11
Metzger, F. R.—J10

Meyer-Schützmeister, Luise—J5
Milton, J. C. D.—E10
Miller, J. M.—U5, UA10, UA11
Miller, L. G.—XA10
Miller, Philip—J3
Miller, Richard D.—B6
Millett, Walter E.—M8, M9
Moak, C. D.—RA1
Moffatt, J.—SA11
Montgomery, D. J.—KA7
Moore, D. C.—B1
Moore, M. S.—XA10
Moore, W. H., Jr.—F2, F3
Morita, M.—GA10
Morris, J. C.—TA5
Morrish, A. H.—BA10
Morton, G. W.—E9
Mosley, H. M.—C2
Mukerji, A.—G9
Muldawer, L.—TA4

Nakada, M. P.—K2
Nathans, R.—FA3, FA4
Nethercot, A. H., Jr.—P6
Netzel, R. G.—V4
Neufeld, Jacob—XA9
Newell, George S.—PA9
Newson, H. W.—K7, K8, K9
Newton, Roger G.—Y3, Y4
Nicol, J.—V1
Nicolai, V. O.—CA1
Nierenberg, William A.—JA1, W1
Nobles, Ralph—XA13
Norton, R. E.—UA3
Novick, R.—W3
Noxon, J. F.—P5
Noyes, H. P.—Y7
Nussbaum, Allen—T8

Obenshain, Felix—E8
O'Brien, Mary—BA4
Ohkawa, Tihiro—C10
O'Kelley, G. D.—G4, G5
Okubo, Susumu—CA9
Olness, J. W.—K11, RA6
Orear, J.—B8, F11
O'Rourke, R. C.—Q4

Pal, Y.—F4
Palevsky, H.—NA12
Pandya, S. P.—GA13
Paris, C. H.—U11
Parker, G. W.—JA4, JA5
Parratt, L. G.—SA6, SA7
Parzen, G.—C8
Paskin, Arthur—BA12
Paul, D. A. L.—M11, M12
Pearce, D. C.—V4
Pearse, C. A.—S2
Pease, Jane—CA8
Pease, Robert L.—CA8
Peaslee, D. C.—MA2
Pelah, I.—NA12
Pell, E. M.—T2
Penfield, R. H.—X5
Penoyer, R. F.—FA2
Pepinsky, R.—FA12, FA13
Percus, J. K.—R10, R11
Perl, M. L.—F1
Perlow, G. J.—E6
Perlman, M. L.—G6
Perlmutter, Arnold—WA9
Petree, Ben—E2
Pevsner, A.—F7
Peyron, M.—P4
Pfann, W. G.—QA2
Phillipp, H. R.—EA2
Phillips, G. C.—J3
Ficus, G. S.—T10, WA8
Pieper, G. F.—U10, XA3
Pilcher, V. E.—NA8, NA10
Pinajian, J. J.—U3
Pipkin, F. M.—VA2
Pirenne, Jean—SA10
Pleasonton, Frances—G1
Pool, M. L.—G8
Porter, W. C.—K6, U4
Porteus, J. O.—SA7
Potnis, V. R.—G9
Pratt, G. W., Jr.—BA5
Preskitt, Charles A., Jr.—K10
Primakoff, H.—MA7, V2
Prosser, F. W., Jr.—U7, U8, U9
Pruett, C. H.—C5, C6
Pugh, E. W.—BA3
Putnam, T. M.—J1

Quinn, J. J.—R9

Rahm, David C.—B10, C9
Rainwater, James—B9, NA5, NA6
Rasmussen, V. K.—J10
Ravenhall, D. G.—D2
Redfield, A.—M1
Reier, Melvin—E7
Reines, F.—A3
Richardson, John M.—R6
Rickey, M.—J7
Riddell, F. R.—H4
Rinehart, John S.—PA1
Riste, T.—FA4
Ritson, D. M.—F7
Rittner, E. S.—N1
Roberts, A.—C3
Roberts, J. H.—K14
Roberts, L. D.—JA4, JA5, VA4
Robertson, W. W.—P1
Rodberg, L. S.—UA5
Rose, David—SA9
Rosen, J.—NA5, NA6
Rosen, Louis—J1, K5
Rosenblum, B.—P6
Rosenson, L.—B2
Ross, B.—WA2
Ross, Marc—MA4
Rossi, Bruno—S5
Roth, Laura M.—TA3
Rothman, M. A.—K6, U4
Rothstein, Jerome—T1
Rubinow, S. I.—Y5
Ruderman, M. A.—UA9
Ruetenik, J. R.—Q8
Russek, Arnold—KA5
Rustad, B. M.—NA11
Rustgi, M. L.—UA7

Sáenz, A. W.—R5
Sailor, V. L.—XA12
Saito, R.—GA10
Salant, E. O.—F10
Salkovitz, E. I.—TA7
Salpeter, E. E.—R12
Sarason, D. E.—E3
Sard, R. D.—B3
Sartori, L.—Y5
Scanlon, W. W.—T7
Schafroth, M. R.—V8
Scharenberg, R. P.—XA6
Scharff-Goldhaber, G.—G10
Scherrer, V.—Q4
Schiffer, J. P.—U7, U9
Schindler, A. I.—TA7
Schluter, R.—F7
Schmitt, H. W.—E11
Schneps, J.—F5
Schubauer, G. B.—H2
Schultz, H. L.—NA1
Schurin, B. D.—TA5
Schwarzschild, A.—G2
Scofield, N. E.—D8, D9
Scott, F.—KA6
Segrè, Emilio—L3
Seigle, L.—WA5
Seth, K. K.—NA10
Seward, F. D.—RA12
Shenker, H.—EA1
Sherr, R.—J7
Shirane, G.—FA4, FA13
Shore, F. J.—XA12
Shugart, Howard A.—JA1
Shull, C. G.—FA3, FA4
Shure, Kalman—E7
Siegel, Armand—FA11
Silsbee, Henry B.—JA1
Silverstein, E. A.—K12
Simpson, F. B.—NA7
Simpson, J. Arol—X9
Singer, S. F.—S1
Slaus, I.—RA12
Smith, Robert T., Jr.—U1
Smither, Robert K.—SA9
Smotrich, H.—RA7
Snell, Arthur H.—G1
Snow, G. A.—F5
Snyder, W. S.—XA9
Soller, T.—V1
Solt, I. H., Jr.—FA7, FA8
Speh, K. C.—E9
Spencer, C. W.—WA5
Spital, S.—D3
Squire, C. F.—EA5
Stearns, B. F.—B3
Stehney, A. F.—E6
Steinberg, M. S.—EA8
Steinberger, D. H.—PA4
Steininger, D. H.—PA4
Stelson, P. H.—J8, XA4
Stephens, W. E.—XA1
Stephenson, Jonn L.—PA2
Sternheimer, R. M.—MA5, UA4
Stevenson, M. J.—JA6
Stewart, Leona—K5
Storm, M.—UA10, UA11
Strand, J.—NA4
Strandberg, M. W. P.—KA9, M3
Stuart, G. W.—CA2
Sudarshan, E. C. G.—MA1
Summers, C. R.—KS6
Sunderland, Robert J.—JA1
Sunyar, A. W.—M7
Swami, M. S.—F5
Swann, C. P.—J10

Taft, E. A.—EA2
Tagliaferri, G.—F2, F3
Talmi, I.—HA2
Tanaka, Katsumi—UA1
Taylor, R. Dean—V3
Taylor, S.—B8, F11
Taylor, T. I.—NA11
Tchen, C. M.—Q2
Tendam, D. J.—K13
Teng, Lee C.—C4
Terwilliger, K. M.—C5, C6
Thresher, J.—SA11
Tiller, W. A.—QA1
Tinlot, J. H.—D3, C7
Toll, J. S.—CA12
Tomnovec, F. M.—G3
Tourin, R. H.—WA11
Trail, C. C.—XA11
Trammel, G. T.—C2
Traughber, R. L.—RA1
Trendelenburg, E. A.—KA3
Turkevich, A.—UA10, UA11

Uzan, R.—X6

Van Patter, D. M.—K6, U4
Van Vleck, J. H.—BA4
Varnerin, L. J.—KA1
Vaughn, M. T.—MA2
Verbinski, V. V.—XA1
Violet, C. E.—F6
Vogt, Erich—GA2
Vorona, J.—K11, RA6

Wagner, M. D.—X9
Walsh, P. J.—SA1
Walter, Robert I.—JA9
Waniek, R. W.—BA1
Ward, A. L.—X7
Wasilik, John H.—EA6
Watt, L. A. K.—BA10
Webb, W. H.—U3
Weber, J.—CA7
Weigand, O. E., Jr.—P1
Weil, J.—J11, RA7, RA9
Weinman, J. A.—C11, K12
Weiss, M.—E2
Weiss, Max M.—JA9
Welker, J.—G6
Welton, T. A.—C12, MA9
Werbrouck, A.—F2, F3
Wertheim, G. K.—T11
Weske, John R.—PA11
Wheeler, J. A.—CA7
White, D. R.—Q5
White, J. A.—M5
White, R. L.—FA7, FA8
White, R. S.—F6
Whitfield, G.—M1
Whittenbury, Clive G.—PA8, PA9
Widgoff, M.—F7
Wigner, E. P.—L1
Wilets, L.—Y8
Williams, Dudley—JA3
Williams, Robert W.—S4
Williams, Ross E.—B9
Willis, William—B10
Wilson, Richard—SA11
Windham, P. M.—C11
Winhold, E. J.—XA1
Wold, D. C.—F5
Wolf, W. P.—BA2
Wolfenstein, L.—MA8
Wolfsberg, M.—G6
Wolga, G. J.—M3
Wong, C.—K2
Wong, D. Y.—CA12
Woods, R. D.—EA4
Worden, D. G.—TA8
Worsham, R. E.—C1
Wu, C. S.—G2, M10, SA4
Wurster, W. H.—Q6

Yagoda, H.—B5
Yeater, M. L.—NA4
Yevick, G. J.—R10, R11
Yockey, Hubert P.—R1
Yu, S. P.—BA10

Zemansky, Mark—L2
Zemel, Jay—WA10
Zimmerman, J. E.—TA2
Zimmerman, R. L.—NA9, NA10
Zorn, B. Sechi—F8
Zorn, G. T.—F8, F10
Zucker, A.—U2, U3

HOTEL INFORMATION

The New Yorker is the headquarters hotel. Reservations should be sent directly to Mr. John Grundhofer, Front Office Manager of the New Yorker, in the manner directed below. Please tear off the attached and use as your room reservation blank. Be sure to specify the persons for whom reservations are being made. All rates quoted are for the room, and in the event of more than one person occupying the room the rate can be shared. If a third person is housed in the room, the cost of the extra "roll-away" bed will be added to the cost of the room.

If a room at the rate requested is not available, one at the nearest available rate will be reserved for you. Be sure to bring the confirmation slip with you as proof of your reservation. In fairness to others, please make a cancellation if your plans change. Unless otherwise requested the hotel will hold reservations only to 6 P.M. of the day of your arrival. Check out time is 3 P.M.

HOTEL RATES

HOTEL	Room and Bath for one per day	Double-Bed Room with Bath for two per day	Twin-Bed Room with Bath for two per day	One Room for 3 persons with bath per day	Suites Living Room Bedroom and Bath for one or two per day
New Yorker 34th Street at 8th Avenue	$8-$12	$10-$15	$13-$18	$15-$18	$25.00 and up

NOTE: All rates subject to New York City 5% hotel room tax.

Tear Off

Tear Off

To: FRONT OFFICE MANAGER
HOTEL NEW YORKER
34TH STREET AND 8TH AVENUE
NEW YORK, NEW YORK

A.P.S.

Please enter my reservation for a single / double / twin bedroom at approx. $..... to $..... per day for the 1957 A.P.S. Meeting. I / We plan to arrive ..... and remain until .....

Print below Persons in Your Party

.....
Signature

.....
Address (Street or P.O.)

.....
Town or City and State

Preliminary Announcement of the 1957 Philadelphia Meeting

In 1957, and probably for the first time in our history, we shall hold two meetings in the month of March. For the earlier of these—the one to be held in Norman, Oklahoma, on March first and second—preliminary announcement was made in the Monterey Bulletin (Series I, Vol. 1, No. 8). The latter will be the usual "March meeting" at which our Divisions of High-Polymer Physics and Solid-State Physics figure so largely. The dates are March 21, 22, and 23; the city is Philadelphia; the scientific sessions will be at the University of Pennsylvania, and the headquarters hotel is the Benjamin Franklin. The rates are $7 to $11 per day for singles, $10 to $14 for doubles, and $14 to $16 for twin-bed rooms.

MEETINGS AND DEADLINES FOR THE YEAR 1957

Place	*Meeting dates*	*Deadline date*
New York	January 30–February 2	past
Norman, Oklahoma	March 1–2	past
Philadelphia	March 21–23	January 18, 1957
Washington, D. C.	April 25–27	February 15
Notre Dame, Indiana	June 20–22	April 12
Boulder,* Colorado	September 5–7	July 8
St. Louis	November 29–30	to be announced
Stanford*	late December	to be announced

* Abstracts for the Boulder and Stanford meetings are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline-day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by air-mail from points east of the Mississippi, and longer for those sent from farther west. To avoid chance of confusion, please do not send an abstract for any meeting until the deadline date of the previous meeting is at least five days past. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.* If, however, members join with nonmembers in the by-line of an abstract, the former are considered to be sponsoring the latter.

RULES PRESCRIBED FOR ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words; each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten and double-spaced; one must be an original, the other may be an original or a carbon copy. Each abstract must be confined to a single page: if it is too long for a single page it is too long to be printed. *Henceforth, if we receive an abstract typed on two pages, we shall print only its first page.* Write each abstract as a single paragraph: the suppression of paragraphs costs time and labor to the editors. Do not use very thin paper; a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. Look at the abstracts in this *Bulletin* to see how the title of the paper and the name of the author are to be arranged, and follow the example. Issues of the *Bulletin* are sometimes appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line. **By action of our Council, abstracts will not henceforth be withdrawn from our proofs unless the asker sends ten dollars with his request.**

Proceedings of the American Physical Society

Minutes of the 1956 Fall Meeting of the New York State Section, Friday and Saturday, October 12 and 13, 1956

THE thirty-sixth meeting of the New York State Section of the American Physical Society was held at the Polytechnic Institute of Brooklyn. Approximately forty-five persons signed the registration lists. Professor P. P. Ewald, head of the Physics Department at the Institute, brought words of welcome. The Friday sessions were followed by an inspection tour of the laboratories at the Institute, a cocktail party in the faculty lounge, and a banquet at Henri Ferrer's restaurant.

The banquet speaker was Professor Pierre Auger, currently director of research at UNESCO. Those attending the dinner enjoyed Professor Auger's remarks concerning the role of the scientist in society and heard with interest his views on problems dealing with the recruiting and training of future physicists.

The splendid program consisting of eight contributed and six invited papers was arranged by Dr. I. Fankuchen, head of the division of applied physics at the Institute. The contributed and invited papers presented at the various sessions are listed below.

D. H. Tomboulian, *Secretary*
New York State Section American
Physical Society
Cornell University, Ithaca, New York

I. Contributed Papers

1. Sonic Velocity in the System Anilene-Cyclohexane in the Critical Solution Region. Marjorie Sobel and F. C. Collins, *Polytechnic Institute of Brooklyn.*

2. Cation Substitutions in Hexagonal Ferri-magnetic Oxides.* R. Summergrad and E. Banks, *Polytechnic Institute of Brooklyn.*

* Supported by the Signal Corps Engineering Laboratories.

3. On the Theory of Electron Transfer Processes.* R. A. Marcus, *Polytechnic Institute of Brooklyn.*—Recently, a quantitative theory[1] was formulated for electron transfer reactions in solution, and a simple expression was obtained for the reaction rate in terms of molecular properties. The theory was devised for reactions in which there is but a small overlap of the electronic orbitals of the two reactants in the collision complex, and it utilized certain expressions obtained for the free energy of media having nonequilibrium dielectric polarization.[2] In the present paper the theory is applied to various oxidation-reduction reactions in aqueous solution, including some involving isotopic exchange. The agreement of the experimental and theoretical results is considered reasonable, no adjustable parameters having been introduced into the calculations. The value of x-ray diffraction, infrared, magnetic, and paramagnetic resonance studies of various hydrates and of other compounds to the detailed understanding of these electron transfer processes is discussed. The relation of these considerations to those involving electron transfer reactions at electrodes and to a recent quantitative theory of overvoltage[3] is noted.

* Supported in part by the Office of Naval Research, Contract Nonr 839(09).
[1] R. A. Marcus, J. Chem. Phys. **24**, 966 (1956).
[2] R. A. Marcus, J. Chem. Phys. **24**, 979 (1956).
[3] Unpublished results.

4. The Hall Effect and Ferromagnetism of Thin Nickel Films.* R. Coren and H. J. Juretschke, *Polytechnic Institute of Brooklyn.*—The electrical and magnetic properties of films of nickel less than 100 A thick have been measured at room temperature. The electrical data show that films prepared under controlled conditions[1] are continuous and of uniform thickness. Magnetic properties were determined using the extraordinary Hall effect.[2] The data have been explained in terms of the theory of a film magnetizing as a single domain,[3] and by extending the resistivity dependence of the extraordinary Hall effect[4] to these films. At room temperature the saturation magnetization in the direction normal to the film plane decreases with decreasing thickness and disappears at about 20 A. At a given thickness the magnetization in this direction is lower than that found in the plane of the film.[1] The direction normal to the film plane is one of hard magnetization.

* Supported in part by the Office of Naval Research.
[1] E. C. Crittenden, Jr., and R. W. Hoffman, Revs. Modern Phys. **25**, 310 (1953).
[2] S. Foner, Phys. Rev. **95**, 652 (1954).
[3] C. Kittel, Phys. Rev. **70**, 965 (1946).
[4] R. Karplus and J. M. Luttinger, Phys. Rev. **95**, 1154 (1954).

5. Coupled Ferromagnetic Resonance. F. K. du Pré, *Philips Laboratories.*—If a ferromagnetic resonance absorption experiment is performed using two adjacent ferrite spheres, one may observe a splitting of the resonance line into a narrow doublet if the strength of the exciting field is different at the positions of the two spheres. Observations on this effect are reported. For one line of the doublet the precessions are in phase, for the other in opposite phase. We have also observed the natural splitting of the ferromagnetic resonance absorption line of only one sphere, the main line being accompanied in our case by two prominent satellite lines occurring at fields a few hundred oersteds lower than the main line. Arguments are presented to show that these satellites are most likely due to opposite phase precessions of two parts of the sphere. This is in agreement with the idea of White, Solt, and Mercereau.[1]

[1] White, Solt, and Mercereau, Bull. Am. Phys. Soc. Ser. II, 1, 12 (1956)

6. Surface States in Crystals. B. A. Lippmann, *Polytechnic Institute of Brooklyn.**—Two topics in the theory of one-dimensional crystals are discussed. (a) Shockley states: Surface states are possible, even in perfect crystals, provided the energy bands have crossed. These levels are regarded as essentially different from states due to surface imperfections. We observe, however, that when energy bands cross, the crystal changes its symmetry: the unit cell shifts, leaving an extra half-cell at each end of the crystal. These half-cells constitute "impurity layers" and give rise to surface levels according to the usual theory. This viewpoint unifies the analysis of

Shockley levels and levels originating from surface imperfections. (b) When are energy crossings possible? For a square well, it is known that the energy must be greater than the potential ($E>V$) everywhere in the unit cell. Utilizing the general behavior of Bloch functions under time and space inversion, we show that a similar result holds for more general potentials: If the potential is real and (for convenience) symmetric, then if E is not $>V$ everywhere in the unit cell, there are no energy crossings and therefore no Shockley levels.

* Now at Eastern Technical Associates.

7. Some Further Work with the Renninger Effect in Crystals. ROBERT S. WILLIAMSON* AND I. FANKUCHEN, *Polytechnic Institute of Brooklyn.*—The azimuthal variation in the intensity of a Bragg x-ray reflection, as a crystal is rotated about a normal to the reflecting crystallographic planes, was shown by Renninger to result from simultaneous occurrence of other reflections. The present studies were undertaken to obtain quantitative information necessary for interpretation of the dynamical interaction among such reflections and to investigate the possibility of direct determination of the relative phases of these reflections. A nondivergent x-ray beam of characteristic copper $K\alpha$ radiation was obtained by successive reflections from two germanium crystals having normal planes of incidence. Geiger counter measurements were made of the reflected intensity from a rotating third crystal of quartz, potassium sulfate, or ammonium sulfate. The observed characteristics of the azimuthal regions of enhanced intensity in weak reflections are similar for crystals of high and low degree of perfection. An asymmetrical angular distribution of increased intensity is observed in many cases. Although increases in the intensity of a strong reflection are not likely to be observed, extinction results in decreases in the intensity of such reflections with both a frequency of occurrence and magnitude previously not fully appreciated.

* Now at Queens College.

8. Sodium in the Upper Atmosphere of the Earth. ROBERT RESNICK, *Rensselaer Polytechnic Institute.*—Recent publicity concerning plans to release sodium into the earth's upper atmosphere from rockets has evoked popular interest. In order to clarify what one hopes to learn from observations on the sodium released in this way, the author will review the difficulties encountered in seeking to understand the role of sodium naturally present in the earth's atmosphere. Such aspects of the problem as the mechanism of excitation of the sodium atoms emitting radiation in the twilight and night sky, the determination of the location and distribution of the sodium atoms, and theories concerning the origin of atmospheric sodium will be discussed. The relationship of this problem to other processes occuring in the earth's upper atmosphere will be mentioned.

II. Invited Papers

1. Use of Counter Tubers in X-Ray Analysis. WILLIAM PARRISH, *Philips Laboratories*

2. Nuclear Resonance in Solids at High rf Power Levels. ALFRED G. REDFIELD, *Watson Scientific Laboratories.*

3. Magnetic Domains in Thin Films. H. J. WILLIAMS, *Bell Telephone Laboratories.*

4. A Travelog of Physics Around the World. CHARLES H. TOWNES, *Columbia University.*

5. Reactors for Research. LYLE B. BORST, *New York University.*

6. High-Energy Physics at the Brookhaven Cosmotron. R. K. ADAIR, *Brookhaven National Laboratories.*

MINUTES OF THE NINTH ANNUAL GASEOUS ELECTRONICS CONFERENCE HELD AT PITTSBURGH, PENNSYLVANIA, OCTOBER 31, NOVEMBER 1, 2, AND 3, 1956

THE ninth annual Gaseous Electronics Conference was held at the Westinghouse Research Laboratories near Pittsburgh, Pennsylvania on October 31, November 1, 2, and 3. The conference was jointly sponsored by the Division of Electron Physics and the Westinghouse Research Laboratories. The highlight of the conference was a symposium on high-temperature plasmas arranged by the conference chairman, W. P. Allis. The titles of the invited papers and the abstracts of some of the 42 contributed papers are printed below. There were 297 registrants.

The conference banquet was held on Thursday evening, November 1. Sanborn C. Brown, of the Massachusetts Institute of Technology, was the after-dinner speaker. He presented a talk on "Count Rumford, the Father of Applied Science."

The Conference Committee for the coming year consists of W. P. Allis (Chairman), Sanborn C. Brown (Secretary), E. F. Lowry, O. Oldenberg, K. B. Persson, and A. V. Phelps.

A. V. PHELPS, *Secretary*
1956 Gaseous Electronics Conference

Contributed Papers

A2. Theory of the Electric Arc at Metals with a Low Melting Point, Such as Copper. RAGNAR HOLM, *Stackpole Carbon Company.*—A consistent theory of the electric arc on metals of low melting points, such as copper and silver, has been achieved. The power balance and the rate of evaporation calculated conform to experimental data. As an important detail, it may be noted that the pressure before the cathode spot has values as high as 10 and 25 atmos. To these saturation pressures correspond elevated boiling points, 3200 to 3800°K, the temperature of the cathode spot. At currents below 50 amp the current density of the positive ions constitutes only a few percent of the total current and the greater portion of the

electron current from the cathode is a field current. At currents of the order of 10^4 amp the positive and negative currents are about equal and the electron emission from the cathode is thermionic, enhanced by the Schottky effect. The complete theory will be discussed in detail in the forthcoming book "Electric Contacts Handbook" to be published early in 1957 by Springer-Verlag in Berlin.

A3. Probe Measurements in the High Intensity Carbon Arc. M. R. NULL AND W. W. LOZIER, *National Carbon Research Laboratories.*—Probe measurements have been made of the voltage distribution in a high intensity carbon arc over a range of arc currents and arc lengths. The voltage drop at the cathode and the voltage gradient across the arc plasma change but little with different arc currents and arc lengths. However, when the spacing between the electrodes is increased, all of the increase in arc voltage does not appear across the arc plasma. Almost one-half (40%) of the increase in voltage is found at the anode itself.

A4. Current Density and Temperature of High Current Arcs. T. H. LEE, W. R. WILSON, AND J. C. SOFIANEK, *General Electric Company.*—A method of measuring the current density of arcs of the order of 20 000 amp is reported. The method consists of placing a small stationary current transformer in the arc plasma. The voltage induced in the current transformer is shown to be proportional to the rate of change of the current linked by the current transformer. The temperature of the arc is calculated from the current density and voltage gradient measurements. A maximum temperature of 19 000°K was obtained. The effects of the current transformer on the arc are discussed. The results are compared with those of Skeats and Schuck. It has been previously reported by Skeats and Schuck that the luminous cones in an arc are not closely related to the current paths in the arc. It is proposed in this paper that the luminous cones are the relatively cool (3000 to 5000°K) vapor jets flowing in the high temperature (20 000°K) "nonluminous" plasma. The narrowing down of the cones indicates the widening of the boundary layer or mixing zone. A very important role for the vapor jets in dissipating the energy input to a high current arc is proposed and its relation to the over-all energy balance is discussed.

A5. Fast Time Analysis of Low Pressure Glow-to-Arc Transitions.* RUSSELL J. WESTBERG, *University of California, Berkeley.*—Initial results on time analysis of transitions from an abnormal glow discharge at about 0.1 to 1 mm relatively pure N_2 and 20 ma current to transient power arcs with hundreds of amperes in a 146-cm long tube studied by one photomultiplier tube viewing the cathode triggering the sweep of a fast synchroscope with a second photomultiplier placed at various points down the tube were reported at the last conference. Techniques have since been perfected to permit measurement of the prebreakdown current, and the potential distribution down the tube as a function of time and position by probes. Complete data over the range of available operating variables have been achieved for relatively pure N_2, N_2–O_2 mixtures, including air, pure A, and pure H_2. Potential drops occur up to 500 and less out of 1760 v applied across the tube and accompany the luminous pulses as they advance down the tube from cathode to anode. Gradients decrease as the pulse advances and are difficult to follow for the reflected pulse of ionization and luminosity moving from anode to cathode. Velocities in the Faraday dark space reach 4×10^8 cm/sec in air. Argon behaves much like N_2. Data accumulated are adequate to permit theoretical analysis of phenomena.

* This work was supported by the Office of Naval Research.

Invited Paper

A7. The Mechanism of the dc-Arc-Column and the Production of High Stationary Temperatures. H. MAECKER, *Siemens-Schuckert Research Laboratories.*

Contributed Papers

B1. Space-Charge Formation and the Negative Townsend Characteristic. A. L. WARD, *Diamond Ordnance Fuze Laboratories.*—Crowe, Bragg, and Thomas[1] have shown that when the steady state current-voltage characteristic of a uniform field gap is modified by space-charge formation, a negative slope region is obtained beyond a certain current. The formulation used by the above authors has been modified only in that α, the first Townsend coefficient, has been changed to depend exponentially upon the inverse square root, rather than the inverse first power of E/P. This dependence allows a satisfactory fit to experimental data over a much wider range of E/P for the rare gases. Static characteristics have been computed for the rare gases for a wide variety of pressures and gap distances, and with some variation of the first and second Townsend coefficients, initial photocurrents, and positive ion mobilities. Numerical computations were made by the National Bureau of Standards Computation Laboratory on SEAC. Comparisons of the computed characteristics with experimental data taken in this laboratory have been made in a limited number of cases. In some cases the agreement is quite good, whereas in other cases there are marked discrepancies.

[1] Crowe, Bragg, and Thomas, Phys. Rev. **96**, 10 (1954).

B2. A Method of Measuring the Mobility Spectra of Negative Ions in Gas Mixtures.* E. W. MCDANIEL, *Georgia Institute of Technology,* AND H. R. CRANE, *University of Michigan.*—A new pulse method of measuring the low-field mobility of negative gaseous ions is described. Negative ions are formed by the capture of the electrons produced in the ionization path of an alpha particle which crosses one end of a long, uniform-field drift tube. The alpha particle enters a proportional counter at the end of its path. The arrival of each individual negative ion at the other end of the drift tube is signaled by a second proportional counter. The first counter triggers the sweep of a synchroscope, and the second counter modulates the beam brightness. A large number of such sweeps is integrated photographically. In each run, with a different gas mixture, a sharp line appears in the photographic spectrum. This gives the drift time for the negative ion in that gas. The mobilities of the negative ions in pure oxygen, and in mixtures consisting of varying percentages of oxygen in He, Ne, A, Kr, Xe, CO_2, N_2, and H_2 were measured and will be discussed. The mobility of the negative ion in pure SF_6 was found to be 0.57 cm^2/v sec. This agrees well with the range for SF_6^- predicted by the Langevin theory including charge exchange, namely, 0.46 to 0.56.

* Supported in part by the U. S. Air Force, Office of Scientific Research of the Air Research and Development Command.

B3. The Temperature Dependence of Ionic Mobilities: Helium, Neon, Argon. L. M. CHANIN AND M. A. BIONDI, *Westinghouse Research Laboratories.*—Measurements have previously been made of the mobilities of atomic and molecular

ions moving in their parent gas for helium[1] and neon[2] at 300°, 195°, and 77°K. The measurements have now been extended to argon. The measured atomic ion mobilities are compared with Holstein's theory[3] in Table I. As in the case of neon, the

TABLE I.

T°K	300°K	195°K	77°K
μ_0 (exptl.) cm²/v sec	1.60	1.95	2.20
μ_0 (theory)	1.65	1.85	2.16

agreement is within the combined errors of experiment and theory. This is in contrast to the case of helium where the experimental results fall below the theoretical values at lower temperatures. The experimental results for the molecular ions are compared with the temperature variations predicted by the Langevin and Hassé-Cook theories. As in the case of neon, the argon values lie intermediate between the limiting cases represented by these theories. For A_2^+ the measured values are 2.7 at 300°K, 2.9 at 195°K, and 2.7 at 77°K.

[1] L. M. Chanin and M. A. Biondi, Phys. Rev. **99**, 1658(A) (1955).
[2] L. M. Chanin and M. A. Biondi, Phys. Rev. **100**, 981(A) (1955).
[3] T. Holstein, J. Phys. Chem. **56**, 832 (1952).

B5. Some Integrable Cases Involving Bimolecular Processes in Gaseous Electronics. JEROME ROTHSTEIN, *Signal Corps Engineering Laboratories.*—If the concentration n (respectively p) of negative (respectively positive) ions, ($n=p$) satisfies $\partial n/\partial t = g - rn^2 + D\nabla^2 n$ (g, r, D, respectively, volume generation, recombination, and diffusion coefficients), then if the diffusion term is approximated by $-n/\tau$, n is given explicitly by

$$n(t) = \left(\frac{g}{r}+\frac{1}{4r^2\tau^2}\right)^{\frac{1}{2}} \begin{matrix}\coth\\ \tanh\end{matrix}\left\{\left(gr+\frac{1}{4\tau^2}\right)^{\frac{1}{2}} t + \begin{matrix}\coth^{-1}\\ \tanh^{-1}\end{matrix}\left[\frac{\left(n_0+\frac{1}{2r\tau}\right)}{\left(\frac{g}{r}+\frac{1}{4r^2\tau^2}\right)^{\frac{1}{2}}}\right]\right\} - \frac{1}{2r\tau}$$

with $n=n_0$ at $t=0$, and coth or tanh applies to $n_0 \gtrless (g/r+1/4r^2\tau^2)^{\frac{1}{2}}$, respectively. For the one-dimensional steady-state problem, governed by $0=g-rn^2+Dd^2n/dx^2$, an explicit solution can be obtained involving Jacobian elliptic functions. D, r, and g are taken independent of concentration. Bimolecularity implies common values of g and r for positive and negative ions; ambipolarity indicates the same for D at high concentration with the latter not necessarily implied by the former. The solution for $n(t)$ will be discussed, showing its relation to more approximate or asymptotic ones in the literature, and how their application outside their sphere of validity can lead to erroneous inferences about the existence of separate fast and slow processes.

Invited Papers

C1. High Temperature Plasma Research: Some Physical Problems and Measurement Techniques. R. F. POST, *University of California Radiation Laboratory.*

C2. Some Theoretical Properties of the Pinch Effect and Its Instabilities. J. L. TUCK, *University of California, Los Alamos Scientific Laboratory.*

C3. Diffusion of Charged Particles Across a Magnetic Field. A. SIMON, *Oak Ridge National Laboratory.*

C4. Some Hydromagnetic Instabilities. M. KRUSKAL, *Project Matterhorn, Princeton University.*

C5. An Energy Principle for the Hydromagnetic Stability Problem. E. FRIEMAN, *Project Matterhorn, Princeton University.*

Contributed Papers

D1. Sputtering Yields for Low Energy Hg^+-Ion Bombardment.* G. K. WEHNER, *General Mills, Incorporated.*—Sputtering yields for normal incident Hg ions were measured in the energy range 30 ev to 400 ev for Au, Ag, Cu, Pt, Ni, Al, Ti, W, Mo, Ta, and Fe. The targets are immersed like large negative Langmuir probes in a low pressure Hg plasma of high density (Hg vacuum arc discharge at 1 μ gas pressure, ion current densities 10 ma/cm²). Absolute yield values are obtained by measuring the weight loss from the target, relative values by measuring the speed with which sputtered material is deposited on a glass collector. By using a glass ribbon, which can be shifted magnetically, a number of measurements can be performed without opening the tube. With yields essentially independent of gas pressure, tube geometry, and ion current density, the scattering of measuring points remains within $\pm 10\%$. Yields above the sputtering threshold are roughly proportional to the ion energy. The slope is essentially determined by the atomic weight, the heat of sublimation, and the crystal structure of the target material.

* This work is sponsored by the Office of Naval Research under Contract NONR 1589(08).

D2. Analysis of Low-Energy Sputtering. E. LANGBERG, *Radio Corporation of America.*—Starting with the assumption that the atomic interaction in metals can be reasonably approximated by the Morse potential[1] the validity of the binary collision mechanism for energy transfer in the lattice is examined. A two-collision sputtering mechanism is postulated for sputtering near the threshold. Under optimum energy transfer conditions, the analysis of this process gives the ion energy for a sputtering threshold of a surface particle tied by N bonds. Under a prolonged ion bombardment a surface contains particles with N ranging from a maximum determined by a complete surface to a minimum determined by inaccessible bonds. Sputtering yield *vs* energy function is derived and shown to consist of a parabolic and a linear part. Predicted and experimental[2] $Pt-Hg^+$ curves are compared. Two thresholds are defined: the actual intercept of the yield curve and the intercept of the extrapolation of its linear part. The two thresholds are computed for twenty metals bombarded by Hg^+ and compared with experiment.[3]

[1] J. C. Slater, *Introduction to Chemical Physics* (McGraw-Hill Book Company, Inc., New York, 1939), Chap. 27.
[2] G. K. Wehner, Advances in Electronics **7**, 239 (1955).
[3] G. K. Wehner, Phys. Rev. **93**, 633 (1954).

D3. Statistical Mechanics of Cathode Sputtering. III. DON E. HARRISON, JR., *University of Louisville.*—This paper is a continuation of the author's statistical treatment of the cathode sputtering problem.[1] New theoretical curves have been calculated from the transport theory, using sputtering thresholds as predicted by Wehner,[2] and fitted to Keywell's experimental data.[3] Satisfactory fitting can be obtained for six systems with mass ratios between 0.04 and 0.80 by varying a

single parameter. The theory is also satisfactory for Kr bombarding Cu, which is the only available set of data for mass ratio greater than unity. The fitting is adequate, but not as good, for the system He-Pb. The theoretical implications of certain new experimental data will be discussed.

[1] D. E. Harrison, Jr., Phys. Rev. **102**, 1473 (1956).
[2] G. K. Wehner, Phys. Rev. **102**, 690 (1956).
[3] F. Keywell, Phys. Rev. **97**, 1611 (1955).

D4. A Novel Form of Hollow Cathode and Its Discharge Characteristics. A. D. WHITE, *Bell Telephone Laboratories, Inc.*—Rare gas discharges to certain types of hollow cathodes have switching and transmission properties which are presently of considerable interest to the field of electronic switching. In addition to the usual high negative resistance (10^4-10^6 ohms) characteristic of discharges at low currents ($10^{-6}-10^{-4}$ amp), these discharges exhibit a second region of negative resistance (10^2-10^3 ohms at speech frequencies) at currents of a few milliamperes. At typical operating pressures of $\frac{1}{10}$ atmos of neon, the current density at the cathode surface is approximately 0.1 amp/cm^2. Under these conditions tube life is limited by the rate at which material is sputtered from the cathode surface. Experimentation with a variety of cathodes had indicated that, for all practical purposes, the effects of sputtering (i.e., cathodic erosion and gas clean-up) are eliminated even at current densities in excess of 0.6 amp/cm^2 by a choice of cathode geometry approximating a spherical cavity having a small aperture. That this is a uniquely stable configuration is suggested by the observation that hollow cathodes of other shapes tend to become spherical during operation of the discharge. The nature of the high-current, negative volt-ampere discharge characteristic will be discussed in terms of plausible physical processes.

D5. Photons in the Negative Glow. D. J. ROSE AND J. EISINGER, *Bell Telephone Laboratories, Inc.*—A tube has been built which permits measurement of electron emission from the cathode by photons produced in a glow discharge. The tube is of parallel plate construction with one movable and one fixed electrode. The latter contains a central region with many small holes drilled at 45°. Behind this perforated region is a small movable parallel plate collector. A coplanar annular guard disk surrounds the fixed electrode, which isolates a discharge in the main gap from the collector region. All parts of the tube seen by the discharge, including the collector, are molybdenum. A glow discharge is run in the main gap with either the fixed or movable electrode as cathode. By measuring the collector current as a function of its potential and gap spacing, one can isolate the effect of photons which penetrate the holes. The photocurrent at the cathode for a given E/p can then be calculated and compared to the main discharge current. For hydrogen, it is large, and a considerable fraction appears to arise from resonance radiation which is attenuated in the molecular gas. Cathode photoemission is about one-half of that arising from ionic secondary emission.

D6. Ionic Oscillations in Hot Cathode Discharges. WALTER J. GRAHAM, *U. S. Naval Research Laboratory.*—A study has been made to determine the mechanism of the low-frequency oscillations frequently observed in hot cathode gas diodes. While at higher currents one encounters conventional relaxation oscillations, the phenomenon of interest here is the existence of rather undistorted sinusoidal oscillations, the frequency of which is independent of circuit reactances. Such oscillations occur predominantly in the "anode-glow" mode, but also in the "ball-of-fire" mode. Measurements (using direct scope observation and also superheterodyne technique) have been made in rare gases, as a function of pressure, current, and cathode temperature. Observed frequencies are in the kilocycles to megacycles range. The results, particularly the drop in frequency with increasing pressure, tend to discount the possibility of ion oscillations of the usual Langmuir-Tonks type, but rather support strongly the suggested hypothesis of ions oscillating in the minimum of the cathode-anode potential profile. Some evidence has been obtained for $1/\sqrt{M}$ dependence by using gas mixtures. Brief mention will be made of the possibility of adapting such a device to diagnostic studies of ion composition of an active discharge (for example to determine the presence of molecular ions).

D7. Vanishing Coefficients in Series Expansions of Periodic Distribution Functions. T. E. VAN ZANDT, *Sandia Corporation.*—When the velocity distribution function is expanded in a series of orthogonal functions, the vanishing coefficients can be determined prior to solving Boltzmann's equation either (a) by reasoning whether each term can or cannot be generated by the applied force, or (b) by requiring that each nonvanishing term be functionally invariant under the same transformations which leave invariant the boundaries and Boltzmann's equation with the given force. The latter condition is briefly derived, and results as obtained with it are presented for several configurations of force and boundaries. For example, if the applied force is the traveling electric wave $\mathbf{E}=\mathbf{E}_0\mathbf{i}\cos(\omega t-\beta z)$ and the boundaries are infinitely distant, the distribution function would be expanded as

$$f(\mathbf{v},\omega t-\beta z)=\sum_{l,m,n=0}^{\infty}[f_{lmn}(v)\cos l(\omega t-\beta z)+g_{lmn}(v)\sin l(\omega t-\beta z)]\cos m\varphi P_n^m(\cos\theta),$$

where $\cos\theta=v_z/v$ and $\tan\varphi=v_y/v_x$; and those coefficients must vanish for which the sum $l+m+n$ is odd.

E1. Probe Measurements of Ionization in Flames. W. E. RICE, I. R. KING, AND H. F. CALCOTE, *Experiment Incorporated.*—Cylindrical probes have been employed in attempts to determine the positive ion concentrations in flames, mostly at atmospheric pressure. Simple Langmuir probe theory predicts many of the observations correctly. The concentrations of ions calculated from the measurements by means of the simple theory must be corrected by the factor a/l, where a is the probe radius and l the mean free path of the ions. Measurements on flames containing known concentrations of alkali metals give values for ion and electron concentrations which agree with those calculated from Saha's equation. These results confirm the use of the correction factor, which is essentially empirical. In addition it is found that experimental and theoretical wall potentials agree, and the electron temperatures are somewhat higher than the adiabatic flame temperature (2800°K and 2270°K). The sheath thicknesses calculated by several procedures are in agreement. However, it is found that the distance of interference of the two probes except in the reaction zone is considerably larger than the calculated sheath thickness and in salted flames is independent of the probe diameter. The resolution of the probe in the reaction zone suggests that the interference distance there is smaller than this. When a second probe is placed 1 cm downstream from the first probe, very little current is detected by the downstream probe, indicating that the rate of ion formation is slow. The work is being continued toward the development of a theoretical understanding of the observations.

E2. Studies of Combustion Zone Ionization Utilizing Focused Electromagnetic Beams. W. W. BALWANZ, *U. S. Naval Research Laboratory.*—Focused low-energy electromagnetic beams used as probes provide a means of studying the conductivity of ionized gaseous media. Such a system is particularly desirable in studying combustion zone phenomena, since the probing beam does not cool or otherwise materially disturb the normal flow of the combustion gases. A 1.25-cm wavelength system has been utilized at the Naval Research Laboratory to conduct exploratory measurements on the

ionization in low pressure combustion zones of acetylene, alcohol, gasoline, ammonia, hydrogen sulfide, carbon disulfide, and hydrogen flames. The fuels were premixed with oxygen and burned in a vacuum chamber at a pressure of between 3 and 4 mm of mercury. A Meker-type burner 4 in. in diameter and 19 in. long, partially filled with glass beads to facilitate mixing, was used. Measurements were made of the absorption of electromagnetic energy propagated through the flame. The experimental results were used to determine the electron densities, which, in some cases, were 6 orders of magnitude greater than the values calculated assuming thermodynamic equilibrium.

E3. Microwave Measurements of High Electron Densities.* S. J. BUCHSBAUM, *Massachusetts Institute of Technology.*—The conventional microwave method for measuring plasma electron densities is limited in its validity to relatively low concentrations (approximately 10^9 cm^{-3}). Following a theoretical development by Persson,[1] a method is presented whereby much higher densities can be measured. The method is based on eliminating the effect of ac space charge on the probing microwave field. This is accomplished by ensuring that the electric field by everywhere perpendicular to electron density gradients and parallel to plasma boundaries. In addition, a discussion is presented on the effect of neighboring modes on the measuring mode in a microwave cavity.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).
[1] K. Persson (to be published).

E4. The Balmer Lines as Indicators of the Physical State of a Plasma.* H. MARGENAU, *Yale University.*—This paper reports new results of a theoretical study concerning the structure of the Balmer lines emitted in a plasma of high ion density. Reliance on the Holtsmark theory leads to two errors: (1) the theory itself requires modifications, and (2) the effect of the electrons becomes important and must be included. We intend to show particularly how point (2) can be treated and how the electrons modify the Holtsmark shape. The departures from that shape depend on the temperature as well as the density of electrons and should provide, in principle, an independent measure of the electron temperature. Point (1) will be left for casual discussion if time permits.

* Work performed under the auspices of U. S. Air Force Research and Development Command.

E5. Further Results on Coulomb Interactions in a Plasma.* HARRY DREICER, *University of California, Los Alamos Scientific Laboratory.*—The Boltzmann-Fokker-Planck transport equation described elsewhere[1] has been solved numerically[2] with nonlinear and integral terms of the equation retained in their exact form. The electronic excitation of molecules is included, but inverse collisions of the second kind have been neglected. The ionization degree, β, is limited to less than 10% so that the effect of electron-ion encounters on resistive heating can be ignored. The effect of electron-electron encounters on the distribution function, average electron energy, and the inelastic collision rate is the problem investigated. Results are given as a function of E/p and β, and the transition of the distribution function from $\beta=0$ to the Maxwellian distribution is shown to occur at a β predicted by energy relaxation rates.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] H. Dreicer and W. P. Allis, Eighth Gaseous Electronics Conference, Schenectady, New York (1955).
[2] I am indebted to Mr. T. Doyle who coded this problem for the IBM 701.

E6. Collisions of Slow Electrons with Atoms and Ions.* A. A. DOUGAL AND L. GOLDSTEIN, *University of Illinois.*—The characteristic time required for equipartition of energy through electron collisions with the ion and atom constituents of the plasma has been investigated experimentally. A guided microwave interaction technique was employed for heating the electron gas to increments above that of the ion and gas temperature, and for probing the plasma during the subsequent transient when the electron temperature relaxes to that of the ions and atoms. The theoretical predictions of Landau,[1] and Spitzer,[2] which are based on appropriate averages over binary electron-ion collisions, for the characteristic time of return to temperature balance due to the long range Coulomb interaction between electrons and ions are verified well within an order of magnitude. In neon at 300°K, 0.9 mm Hg, 5.5×10^{11} ions per cm^3, the characteristic time of equipartition is 16 μsec, being predominantly determined by energy exchange through electron-ion collisions.

* Supported by the A. F. Cambridge Research Center.
[1] L. Landau, Physik. Z. Sowjetunion **10**, 154 (1936).
[2] L. Spitzer, Jr., *Physics of Fully Ionized Gases* (Interscience Publishers, Inc., New York, 1956).

E7. Non-Maxwellian Electron Energy Distributions in Plasmas, Determined by a New Graphical Method. G. MEDICUS, *Advanced Development Branch.*—As described previously,[1] the electron energy distribution in plasmas for approximately isotropic electron velocities is quickly obtained graphically from probe curves. Precise evaluations of probe curves from hollow hot cathode diodes with 1 mm Ne showed a fast electron group entering the plasma through a cathode fall of 16 to 17 v, gaining small additional energy in the plasma fields and ionizing cumulatively through the 16.6-v metastable Ne level. The secondaries constitute a slow group which is Maxwellian at least up to about 4 times the mean thermal energy, E_T, with temperatures from about 2000°K at the lowest ($\approx$10 ma), up to 30 000°K and more at high ($\approx$0.5 amp) diode currents. Once the originally fast electrons are slowed down to 4–5 E_T, they are integrated into the Maxwellian part of the distribution. The higher the diode currents, the more the total distribution approaches a Maxwellian, ionization by the fast Maxwellians predominating over that by the cathode fall electrons. The study of the energy exchange between the two groups, facilitated by the new graphical method, will furnish fundamental information on the generation of the common Maxwellian distribution of plasma electrons.

[1] G. Medicus, J. Appl. Phys. **27**, 1242 (1956).

E8. Plasma Oscillations in a Magnetic Field. IRA B. BERNSTEIN, *Project Matterhorn, Princeton University.*—The small oscillations of a completely ionized plasma in a constant external magnetic field are treated by the Laplace transform method. The full set of Maxwell equations is employed. The ion dynamics are included and are shown to have a very small effect on the frequencies as long as the ion and electron temperatures are equal. The limit of pure electron oscillations is considered. It is concluded, in contradiction with the results of Gross,[1] that there is no damping of waves propagating perpendicular to the external magnetic field, and, in contradiction with the conclusion of Gordeyev,[2] that there can be no self-excitation of oscillations about thermal equilibrium.

[1] E. P. Gross, Phys. Rev. **82**, 232 (1951).
[2] G. V. Gordeyev, J. Exptl. Theoret. Phys. (U.S.S.R.) **6**, 660 (1952).

E9. Plasma Oscillations in dc Discharges.* E. I. GORDON, *Massachusetts Institute of Technology.*—A general result for the conductivity of a plasma when the rf field exists in a region not necessarily large compared to a mean free path is shown to be

$$\sigma=-\frac{4\pi}{3}\frac{ne^2}{m}\int_0^\infty[(j\omega+\nu_c)^{-1}-(j\omega+\nu_c)^{-2}3v/4d]v^3\partial f/\partial v dv,$$

where n is the electron density, ω the angular frequency, d the width of the region, $\nu_c(v)$ the collision frequency, and $f(v)$ is the isotropic velocity distribution. In analogy with Margenau's

result, this leads to an effective collision frequency $\nu(v)=\nu_c(v)+3v/4d$, so that the damping of plasma oscillations is pressure dependent only when the mean free path is comparable to d (order of a mm). It is shown that under conditions satisfied only in the sheath-plasma boundary region, a monoenergetic beam of electrons may have a conductivity whose real part is negative. Consequently, the beam could supply sufficient energy to maintain the oscillations if the beam current density is greater than a minimum value proportional to ω^3. Results for double beam oscillations are also described and compared with experiment.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

F1. Electron Energy Distribution in the High-Frequency Multipacting Mechanism.* ALBERT J. HATCH† AND H. BARTEL WILLIAMS, *New Mexico College of Agriculture and Mechanic Arts.*—A previously developed statistical theory[1] of electron multiplication in the high-frequency low pressure multipacting breakdown mechanism (secondary electron resonance) has been extended to the calculation of the energy distribution of electrons arriving at an electrode surface. Electron arrival energy distributions have been calculated for aluminum electrodes at a 3-cm separation and applied 70 mc/sec voltages of 150 and 600 peak v. The 150-rf v distribution has a minor peak at 35 ev due to $\frac{3}{4}$ cy transit time electrons and a major peak at 100 ev due to $\frac{1}{4}$ cy electrons. The 600-rf v distribution has only a major peak at 470 ev due to $\frac{1}{4}$ cy electrons. Experimentally determined electron arrival energy distributions have been obtained at 10^{-4} mm Hg pressure by an electrostatic filter analysis of electrons emerging from a small sampling aperture in a multipacting electrode. The observed energy distributions for parameters as above compare favorably with the theoretical distribution.

* Work supported by the Bureau of Ordnance, U. S. Navy.
† Now at Argonne National Laboratory, Lemont, Illinois.
[1] A. J. Hatch and H. B. Williams, Phys. Rev. **89**, 339(A) (1953).

F3. Effect of Magnetic Field on High-Frequency Electrodeless Discharge at Low Pressure. ELSA L. HUBER, HOWARD T. OZAKI, AND ALFRED KLEIDER, *Hughes Research Laboratories.*—The influence of magnetic fields ranging from zero to 100 oersteds on starting potentials of the high-frequency low-pressure electrodeless discharge has been examined. Data will be presented for two flat-ended cylindrical Pyrex discharge tubes of lengths 1.6 and 2.8 cm containing air at 10^{-5} mm Hg. The tubes were placed in crossed dc magnetic and rf electric fields at frequencies of 10 to 100 mc/sec. For small magnetic fields, curves of starting voltage *vs* frequency have the same general shape as for zero field, but they are shifted toward higher voltages and the cut-off frequency is lowered. Once the discharge is started, it can be extinguished again either by increasing the voltage or decreasing the magnetic field. Combined curves of starting and exctinction voltages define the boundaries of a breakdown region in either the voltage-frequency or the voltage-magnetic field plane. At higher magnetic fields, starting voltages become sensibly independent of frequency. A qualitative interpretation will be given in terms of the secondary electron resonance phenomenon.

F4. Breakdown of Air at Microwave Frequencies.* LAWRENCE GOULD AND LOUIS W. ROBERTS,† *Microwave Associates, Inc.*—A theory for uniform field breakdown in air at microwave frequencies is developed and applied with success to predicting values of breakdown over a wide range of experimental conditions. Three distinct types of breakdown are treated: C.W. (continuous wave) breakdown, single pulse breakdown, and multipulse breakdown. The conditions for breakdown are determined from a solution of the electron continuity equation for an average electron in which electron ionization, attachment, and diffusion are the dominant mechanisms. Modulation of the electron average energy at twice the frequency of the applied field becomes important at either high pressure or low frequency and modifies the values of the breakdown field. The breakdown field strengths are shown to be determined from a single curve for each type of breakdown power, either C.W. or pulsed. These theoretical curves are in accordance with the experimental results, thus verifying the assumptions and the values of the coefficients used in the theory.

* This work was supported by the Bureau of Ships under Contract NObsr-63295.
† Now at Bomac Laboratories, Incorporated, Beverly, Massachusetts.

F5. Anode Streamers Observed in Steady Potential Breakdown at Low Overvoltages for Gaps Ranging from Point-to-Plane to Uniform Fields in Air.* G. G. HUDSON AND L. B. LOEB, *University of California.*—The sequence of luminous events in the breakdown of various gap forms in room air at atmospheric pressure with steady potential as revealed by a photomultiplier placed at various points along the gap, the fast oscilloscope sweep being triggered by another photomultiplier viewing the anode, was reported in preliminary fashion at the last Conference. Techniques have been improved and extended to include sparks between 31 cm diam spheres and planes with gaps ranging from 0.5 to 9 cm long, using a small air blast driven Van de Graaff generator to reduce electrical noise. For overvoltages, less than 2% of *all* sparks were initiated by *streamer sequences starting from the anode.* Time, intensity, and position data permit pulse form and velocity for primary and secondary streamers to be measured by cross plots. Following arrival of the secondary in vicinity of the cathode, there results the brilliant main stroke whose direction of motion can, in some instances, be determined and appears to vary with gap geometry. That is, the main stroke appears not always to start from the cathode on arrival of the secondary streamer, but may start from the anode or simultaneously from anode and cathode. More accurate information is beyond resolving power of the equipment.

* This work was supported by the Office of Naval Research.

F6. Experimental Evidence for the Existence of Secondary Ionization in Oxygen at High Pressure.* D. J. DEBITETTO AND L. H. FISHER, *New York University.*—Townsend's second ionization coefficient, γ, has been previously measured at pressures as high as half an atmosphere in air, nitrogen, and hydrogen.[1–3] Ionization currents in strongly attaching gases have been shown to depend on an attachment coefficient, η.[4] Thus to determine γ in an attaching gas, current-voltage measurements must be analyzed to yield three coefficient, γ, η, and the first Townsend coefficient, α. The equation for current simplifies enormously when $\alpha=\eta$, allowing an unambiguous determination of γ. This has been carried out for oxygen at an E/p of 35.4 (at which we find $\alpha=\eta$) yielding a value of γ of approximately 0.045 at a pressure of 300 mm Hg. This is more than an order of magnitude larger than the values of γ previously found in hydrogen and nitrogen for the same nickel cathode.[3]

* Supported by the Office of Naval Research.
[1] F. Llewellyn Jones and A. B. Parker, Proc. Roy. Soc. (London) **A213**, 185 (1952); Dutton, Haydon, and Llewellyn Jones, Proc. Roy. Soc. (London) **A213**, 203 (1952).
[2] Wilkes, Hopwood, and Peacock, Nature **176**, 837 (1955); Crompton, Dutton, and Haydon, Proc. Phys. Soc. (London) **B69**, 2 (1956).
[3] D. J. DeBitetto and L. H. Fisher, Phys. Rev. **100**, 1227 (1955).
[4] M. A. Harrison and R. Geballe, Phys. Rev. **91**, 1 (1953).

F7. The Breakdown Mechanism of the Long Laboratory Spark. E. HOWARD HOLT,* *Associated Electrical Industries Ltd.*—The work of Allibone and Meek[1] and of Norinder and Salka[2] on the mechanism of long-gap spark breakdown of air at atmospheric pressure using the laboratory impulse generator has been extended. A catadioptric camera of nominal aperture

$f/1.85$ and with the transparency of a quartz lens[3] enabled photographs of partially developed discharges to be taken containing significantly more detail than those obtained in previous work. The simultaneous recording of oscillograms showing the growth of current in the test gap enabled a close correlation to be made between the interpretations of the photographs and the oscillograms. A time resolution of the discharge development in the 3-ft, 6-in. rod gap was obtained by "chopping" the impulse generator output by a parallel sphere-gap after a predetermined time. In addition to electron avalanches and positive and negative streamers, whose roles have been previously established, "threads" of discharge associated with positive streamers were photographed and their role of aiding the growth of conduction current in the gap before the main stroke occurs was established by the interpretation of the current oscillograms.

* Now at the Electrical Engineering Research Laboratory, University of Illinois, Urbana, Illinois.
[1] T. E. Allibone and J. M. Meek, Proc. Roy. Soc. (London) **A166**, 97 (1938); Proc. Roy. Soc. (London) **A169**, 246 (1938).
[2] H. Norinder and O. Salka, Arkiv. Fysik **3**, 347 (1952); Arkiv. Fysik **5**, 493 (1952).
[3] J. Dyson, J. Sci. Instr. **32**, 272 (1955).

G1. Microwave Determinations of the Frequency of Ionization and the Coefficient of Free Diffusion in Hydrogen.* M. P. MADAN, S. J. BUCHSBAUM, AND E. I. GORDON, *Massachusetts Institute of Technology.*—Microwave breakdown experiments yield, apart from other parameters, the ratio ν_i/D_-, in which ν_i is the ionization frequency and D_- is the coefficient of free diffusion for electrons. This paper describes a method for a direct determination of ν_i and D_-, utilizing an additional experimental parameter tp, where p is the pressure and t is the time for the buildup of electron density. In addition, the steady-state breakdown fields can also be predicted. The experiment has been performed, using two TM_{010}-mode resonant cavities of different sizes. The results have been compared with the theory of Allis and Brown. By properly accounting for the space-charge effect and the nonuniformity of the electric field, the results are in substantial agreement with the theory.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).

G2. Physical Principles Underlying Very-High-Output Fluorescent Lamps. JOHN F. WAYMOUTH, *Sylvania Electric Products Inc.*, AND FRANCIS BITTER, *Massachusetts Institute of Technology.*—Fluorescent lamps generate light by the conversion of ultraviolet radiation from a mercury-rare-gas discharge into visible light by a phosphor on the walls of the tube. With present-day phosphors, the factor limiting the maximum light output obtainable is the amount of ultraviolet radiation per unit length which can be produced by the discharge. Two factors limit the amount of ultraviolet radiation. First, the efficiency of production of uv decreases for mercury vapor pressures above 6 to 10 μ, and hence, the condensed mercury temperature must be kept low (40°C). In the past, this has meant that total lamp power input was limited to about 10 to 15 w per foot, to keep the bulb-wall temperature at 40°C. Second, even at constant mercury vapor pressure, the ultraviolet radiation approaches a saturation value (which is determined by the electron temperature) as the power input is increased. In order to produce high output, therefore, it is necessary to have the electron temperature as high as possible. The factors influencing the electron temperature are discussed, and a practical way of increasing it is described. A simple means of providing the correct mercury vapor pressure is described.

* This work was done at the Sylvania Electric Products Inc. Laboratories.

G3. Microwave Conductivity Measurements in Neon Contaminated with Argon.* ALDO L. GILARDINI,† *Massachusetts Institute of Technology.*—The method used by Gould and Brown[1] for determining the electron collision probability for momentum transfer in helium by measuring the microwave conductivity of a decaying plasma as a function of the electron energy, controlled by a microwave heating field, has been used for determining the same parameter in neon. In this case, due to the smaller value of the electron collision probability and the larger atomic mass of neon as compared to helium, energy gradients produced by the heating field nonuniformities are very important in determining an energy redistribution inside the plasma. The conditions required for having a pressure independent ratio of the real to the imaginary part of the complex conductivity and for reaching steady-state electron energy conditions are theoretically investigated. From the measured microwave conductivity in neon contaminated with argon, the electron collision probability in neon has been computed as a function of the electron energy; the curve joins Ramsauer and Kollath's[2] measurements for higher electron energies.

* This work was supported in part by the Army (Signal Corps), the Air Force (Office of Scientific Research, Air Research and Development Command), and the Navy (Office of Naval Research).
† National Science Foundation Foreign Fellow, on leave from Instituto Superiore PP. TT., Rome, Italy.
[1] L. Gould and S. C. Brown, Phys. Rev. **95**, 897 (1954).
[2] C. Ramsauer and R. Kollath, Ann. Physik **12**, 529 (1932).

G5. Spectral Line Width and Dissociative Recombination in a Helium Afterglow. W. A. ROGERS AND M. A. BIONDI, *Westinghouse Research Laboratories.*—The width of the $\lambda 5876$ line of atomic helium has been studied as a function of pressure in the early afterglow of a pulsed microwave discharge. If the afterglow radiation is the result of dissociative recombination of diatomic helium ions with electrons, it was predicted[1] that the afterglow line width must exceed that of the active discharge because of the kinetic energy imparted to the excited atom in the act of dissociation. Although this prediction was corroborated, the pressure dependence of the afterglow width did not appear to fit the dissociative recombination hypothesis. The apparent continued increase in afterglow line width at higher pressures was shown to be the result of the appearance of helium molecular bands which distorted the interferometer pattern. At low pressures, the line width decreased with no change of intensity. This behavior could not be attributed to recombination of atomic ions, nor to production of the 3^3D state by cascading from higher atomic states. It is probably due to excitation of metastable atoms during the afterglow by electrons of 3 ev or more kinetic energy. From the maximum observed line width, the energy of mutual repulsion of the two atoms dissociating is found to be greater than 0.08 ev.

[1] W. A. Rogers and M. A. Biondi, Phys. Rev. **99**, 1657(A) (1955).

G6. The Free Electrons in Active Nitrogen.* W. B. KUNKEL, *University of California, Berkeley, California.*—It has been proposed that the free electrons usually found in active nitrogen are generated by ionization of nitric oxide molecules[1] either in binary collisions with metastable nitrogen molecules or in triple collisions with two nitrogen atoms. This interpretation has been verified by measurement of the electron density in a stream of active nitrogen at various pressures when known amounts of nitric oxide are injected. It has been demonstrated that at high electron densities, the charge removal proceeds by recombination, while at low densities, diffusion prevails. The estimated rate constants for the ionizing reactions seem reasonable (of the order of 10^{-29} cm^6 sec^{-1} for the three-body collisions) provided the nitric oxide molecules are not simultaneously removed by rapid non-ionizing reactions with the active nitrogen. So far, attempts to detect the nitric oxide ions directly in a mass spectrograph have been unsuccessful. Injection of minute traces of benzene vapor removed practically all

electrons but enhanced and prolonged the afterglow. Hence it is concluded that the visible emission is not induced by the free electrons.

* Work supported by Wright Air Development Center.
[1] W. B. Kunkel and A. L. Gardner, Phys. Rev. **98**, 558 (1955).

G7. Short Duration Afterglow of Nitrogen.* R. B. BRYAN, R. B. HOLT, AND O. OLDENBERG, *Harvard University.*—In the afterglow of a low-pressure discharge through nitrogen the *spectrum* and the *intensity* of the light emitted were observed with a "shutter speed" of 100 μsec through a period of 1500 μsec. The data were correlated with the decay of the *electron-ion concentration*. The spectrum is essentially identical with that of Kaplan's "auroral afterglow." It contains most of the prominent band systems, including N_2^+ bands. The Herman bands between 7000 and 8000 A appear with considerable intensity. The spectra are excited only to a minor extent by electron-ion recombination, but largely by the recombination of two active particles, some of them metastable. In oxygen under the same conditions very little light is emitted.

* Supported by the Geophysics Directorate of the A. F. Cambridge Research Center and the Office of Naval Research.

MINUTES OF THE FALL MEETING OF THE NEW ENGLAND SECTION HELD AT THE UNIVERSITY OF CONNECTICUT, STORRS, CONNECTICUT, ON NOVEMBER 3, 1956

THE New England Section of the American Physical Society held its annual Fall Meeting on Saturday November 3, at the University of Connecticut, Storrs, Connecticut. Four invited papers were heard at the morning session:

Measurement of Large-Angle Ion-Atom Scattering at Energies up to 100 kev. EDGAR EVERHART, *University of Connecticut.*

Theory of Ion-Ion Scattering. ARNOLD RUSSEK, *University of Connecticut.*

Heat Transfer in Helium II. C. A. REYNOLDS, *University of Connecticut.*

Institutes for the Improvement of Secondary School Teaching, Sponsored by the National Science Foundation. M. J. WALKER, *University of Connecticut.*

Following a luncheon, the facilities of the University of Connecticut, Department of Physics were open for inspection.

At the afternoon business session the following Council Members were elected to serve until the next Fall Meeting:

Chairman:	J. K. Knipp (Tufts)
Vice Chairman:	R. P. Winch (Williams)
Secretary-Treasurer:	R. F. Kingsbury (Trinity)
Executive Committee:	N. C. Little (Bowdoin)
	P. E. LeCorbeiller (Harvard)

Following the business session, the retiring Chairman of the section, H. P. Knauss (University of Connecticut), presented an address, "Electron Bombardment of Bacterial Spores." After this address six contributed papers were presented.

ROBERT F. KINGSBURY, *Secretary-Treasurer*
New England Section

Contributed Papers

1. A V.H.F. Super-Regenerative Spectrometer.* P. A. CASABELLA† AND P. J. BRAY, *Brown University.*—A very-high-frequency super-regenerative spectrometer has been constructed using a butterfly condenser rather than the tuned transmission lines which have been employed for this type of circuit in the past. The butterfly condenser is a complete tuned circuit, containing both inductance and capacitance, and has a much wider frequency range than other types of circuits. The spectrometer described in this paper covers the frequency range from slightly below 100 Mcps to above 400 Mcps. There is no electrical contact between the rotor of the condenser and the rest of the circuit. Thus the problem of the noise from sliding contacts which is often troublesome in tuned line spectrometers is eliminated. Several resonances have been observed with this spectrometer and the results are found to compare favorably with those observed on tuned line spectrometers. A second super-regenerative spectrometer employing a higher frequency butterfly condenser has reached frequencies above 700 Mcps.

* This work was supported by a Frederick Gardner Cottrell Grant from the Research Corporation.
† This work, carried out at Brown University, forms part of a thesis submitted to Rensselear Polytechnic Institute in partial fulfillment of the requirements for the Master of Science Degree.

2. Pure Quadrupole Resonances in Chloroparaffins.* S. MOSKOWITZ AND P. J. BRAY, *Brown University.*—Using a self-quenching super-regenerative spectrometer, pure quadrupole resonance frequencies have been measured for Cl^{35} in various solid chloroparaffins. Since these transition frequencies are proportional to $eqQ_{Cl^{35}}$, the coupling constant for the Cl^{35} atom where q is the principal component of the electric field gradient tensor and $eQ_{Cl^{35}}$ is the electric quadrupole moment of the nucleus, it is possible to determine the variation of q from molecule to molecule. Allowing for the influence upon q of the crystal structure, it is possible to examine the nature of the carbon-chlorine bonds in the various molecules. Original investigations of the chloromethanes and chloroethanes initiated by R. Livingston[1] have been extended to chloropropanes, chlorobutanes, and chloroheptane. Questions pertaining to the degree of *p-s* orbital hybridization of the covalent chlorine-carbon bond and the amount of ionic character of the bond are, in part, answered on the basis of the experimental results.

* This work was supported by a grant from the National Science Foundation.
[1] R. Livingston, J. Phys. Chem. **57**, 496 (1953).

3. Comparison of Factors Affecting Quantification of Soft Roentgen Rays. PAUL J. ROSENBAUM, *Yale University School of Medicine.*—Quantification of relatively long wavelength x-rays has always been difficult and of increasing importance of late. Studies were made of the variations in recorded x-ray outputs resulting from different thimble chamber materials, different condenser roentgen meters of the same type, and increasing filtration of extremely soft x-rays. Comparisons

were also made using a well-filtered relatively energetic soft x-ray beam. Some theoretical explanations for discrepancies are noted.

4. Atomic Heats of Normal and Superconducting Thallium.* J. L. SNIDER† AND J. NICOL, *Amherst College.*—The atomic heats of thallium have been measured in the liquid helium temperature range. In the normal state the atomic heat varies with temperature according to the form,

$$C_n = \gamma T + 464.4(T/\theta)^3 \text{ cal/mole-deg},$$

in which $\gamma = 6.11 \times 10^{-4}$ cal/mole-deg^2 and $\theta = 86.6°$. In the super conducting state, at temperatures below $0.8T_c$, the electronic specific heat obeys the relationship,

$$C_s' = \gamma T_c A \exp(-\alpha T_c/T) \text{ cal/mole-deg},$$

in which $A = 5.8$ and $\alpha = 1.3$. These results lend support to the suggestion made in consequence of recent measurements of the atomic heats of vanadium,[1] tin,[2] and aluminum[3] that the electronic specific heat in the superconducting phase may in general be an exponential function of the temperature. It is pointed out that over a restricted temperature range the superconducting electronic heat of indium[4] may also be represented by a similar expression in which $A = 9.6$ and $\alpha = 1.6$. The measurements on thallium do not confirm the suggestion that there exists a law of corresponding states among superconductors.[2]

* Work performed as part of low-temperature physics program supported by the Research Corporation and the National Science Foundation.
† Now at Princeton University.
[1] Corak, Goodman, Satterthwaite, and Wexler, Phys. Rev. **102**, 656 (1956).
[2] W. S. Corak and C. B. Satterthwaite, Phys. Rev. **102**, 662 (1956).
[3] B. B. Goodman, *Conférence de Physique des Basses Températures* (Paris, 1955), p. 506.
[4] J. R. Clement and E. H. Quinnell, Phys. Rev. **92**, 258 (1953).

5. Counter Investigation of the Second Maximum in the Cosmic-Ray Rossi Curve. S. P. SHEN,* *Clark University.*—The controversial second maximum in the Rossi curve was investigated using three Geiger-Muller counter tubes arranged in triple coincidence. One tube was placed 4 cm below the lead absorber and the other two side-by-side 43 cm directly below the first and 19 cm above the floor (wood), all tube axes being mutually parallel. The measurements, obtained at 54°N geomagnetic latitude (elevation 170 m) under a roof of ~8 g·cm^{-2}, showed some fluctuations, but no convincing evidence of a second maximum. However, a slight accidental shift in counter geometry was accompanied by an unexpected over-all change in coincidence rates; both this change and the general elusiveness of the second maximum, it is suggested, might be partially ascribed to the complex statistical uncertainty concerning the percentage of showers (of various densities and angular spreads) actually recorded by a counter system of *finite* dimensions. It is further suggested that the problem of the second maximum may be one of detection rather than of existence, and that the failure to detect it by numerous workers was probably caused by ever so slightly unfavorable geometry.

* Now at the State University of New York, College for Teachers at Albany.

6. Diffraction Pattern Caused by Secondary Mirrors and Their Supports in Reflecting Telescopes. JOSEPH KANTORSKI* AND EDGAR EVERHART, *University of Connecticut.*—The presence of a secondary mirror and its supports in a reflecting telescope causes considerable change in the diffraction pattern, which is the image of a star. Photographs have been made showing in detail the modification in the pattern caused by central obstructions of various diameters and by supporting members of several widths. For example, a clear aperture causes 84% of the light energy to appear in the central disk with 16% in the rings, whereas a central obstruction whose diameter is $\frac{1}{4}$ the aperture causes only 73% of the light to be in the central disk and 27% in the rings. This effect is investigated theoretically for a wide range in proportion and is confirmed photographically. The diffraction spikes caused by supporting members of various number and orientation are illustrated. Recommendations are made concerning the designs which minimize undesired diffraction effects.

* Now with the American Optical Company.

Regulations Pertaining to the "Student Concession"

THE "student concession" is the alleviation of the financial burden of Membership in the American Physical Society, granted to newly elected Members who are students in recognized institutions of learning. It was instituted in 1952, and our Council has now (April 27, 1956) made important changes in the rules that define it and in the stipulations that define eligibility to it. Henceforth it shall consist (a) in a reduction of the dues from fifteen dollars to ten dollars, and (b) in the privilege of obtaining *one* journal, among those made available to all members on "membership subscription," without extra payment over and above the dues. It will be granted for one year only, and this must be the first year of Membership.

To be eligible for the "student concession," a candidate must (1) be a full-time student in a recognized institution of learning, and (2) present a certification by one of his sponsors that he is in fact such a student. On the nomination forms which have been printed during the last couple of years there is a certification (on the reverse side) which the sponsor must sign: it is however to be borne in mind that the words "bona fide student regularly enrolled" are now to be interpreted as meaning "full-time student," and that the special privilege is now limited to one year. Unfortunately there are many nomination forms of more ancient vintage still floating around. If one of these is used, the certification must be made in a covering letter signed by one of the sponsors, and this covering letter must be mailed in the same envelope as the nomination form.

These rules and stipulations will apply to candidates elected to Membership in November 1956 and thenceforward. Nomination forms for a number of candidates have been received at the office of the Society for action at the Annual Meeting: if the sponsors of such a candidate wish to propose him for the "student concession" but have reason to think that stipulation (2) has not been fulfilled, or if they did certify him but he is ineligible under the strict formulation of stipulation (1), they should at once recall his nomination form from this office and take heed of these stipulations before sending it back. Candidates who were elected to Membership at any time in the first six months of 1956 and who were granted the "student concession" for 1956 have a right to retain it for 1957: in such case it consists simply of the privilege of receiving one journal on membership subscription without extra payment over and above dues, and the dues themselves stand at the normal figure of fifteen dollars.

The American Physical Society

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COUNCIL

The President, Vice-President, Secretary, Treasurer, Managing Editor, the three Past Presidents most recently retired from office, eight elected members, and all Past Presidents first elected to the office of President prior to December 1932 constitute the Council which shall have general charge of the affairs of the Society.

Past Presidents now on Council: W. F. G. Swann, H. A. Bethe and R. T. Birge.

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